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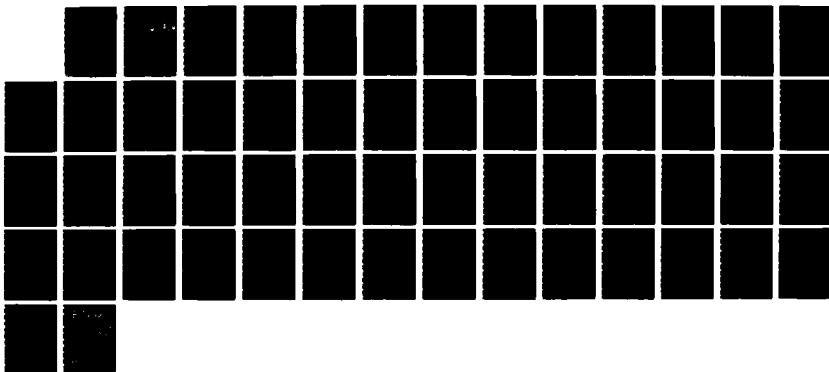
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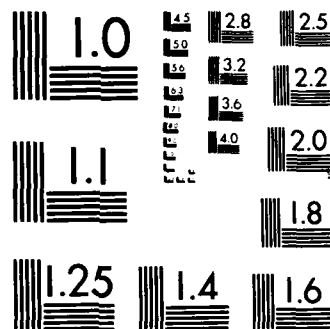
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Monterey, California



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## THESIS

PERFORMANCE EVALUATION OF A HALF-WAVE  
PERSONANT SLOT ANTENNA OVER PERFECT  
GROUND  
USING NEC

by

Constantinos Theofanopoulos

March 1987

Thesis Advisor

R.W. Adler

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Prepared for: Naval Ocean Systems Center, San Diego, California 92152

87 9 1 320

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This thesis is prepared in conjunction with research  
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Gordon E. Schacher  
Dean of Science and Engineering

## REPORT DOCUMENTATION PAGE

1a REPORT SECURITY CLASSIFICATION <b>UNCLASSIFIED</b>		1b RESTRICTIVE MARKINGS	
2a SECURITY CLASSIFICATION AUTHORITY		3 DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution is unlimited	
2b DECLASSIFICATION/DOWNGRADING SCHEDULE		4 PERFORMING ORGANIZATION REPORT NUMBER(S) NPS-62-87-011	
5 MONITORING ORGANIZATION REPORT NUMBER(S)		6a NAME OF PERFORMING ORGANIZATION Naval Postgraduate School	
6b OFFICE SYMBOL (If applicable) 62		7a NAME OF MONITORING ORGANIZATION Naval Postgraduate School	
6c ADDRESS (City, State, and ZIP Code) Monterey, California 93943-5000		7b ADDRESS (City, State, and ZIP Code) Monterey, California 93943-5000	
8a NAME OF FUNDING/SPONSORING ORGANIZATION Naval Ocean Center Systems Center		8b OFFICE SYMBOL (If applicable) Code 825	
9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER N6600186WR00516		10 SOURCE OF FUNDING NUMBERS	
8c ADDRESS (City, State, and ZIP Code) San Diego, California 92152		PROGRAM ELEMENT NO	PROJECT NO
		TASK NO	WORK UNIT ACCESSION NO
11 TITLE (Include Security Classification) PERFORMANCE EVALUATION OF A HALF-WAVE RESONANT SLOT ANTENNA OVER PERFECT GROUND USING NEC			
12 PERSONAL AUTHOR(S) THEOFANOPOULOS, Constantinos			
13a TYPE OF REPORT Master's Thesis	13b TIME COVERED FROM TO	14 DATE OF REPORT (Year Month Day) 1987 March	15 PAGE COUNT 55
16 SUPPLEMENTARY NOTATION			
17 COSAT CODES		18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)	
FIELD	GROUP	SUB-GROUP	
		Survivable antennas	
19 ABSTRACT (Continue on reverse if necessary and identify by block number) Present and future trends in shipboard antenna designs have as an objective, antennas which are or will be survivable in combat environments, integrable in ship's superstructures, low in profile and compact. This thesis investigates the performance characteristics of a 7 by 0.2 meter slot antenna, which is cut into a rectangular bulkhead, the bulkhead being a section of the superstructure of an average ship. This slot antenna was modeled using the Numerical Electromagnetic Code. Input impedances, radiation patterns and near fields inside the slot are presented. The reason for conducting this performance evaluation is to determine if this approach to survivable antennas is feasible enough to be implemented in future ship designs.			
20 DISTRIBUTION/AVAILABILITY OF ABSTRACT <input checked="" type="checkbox"/> UNCLASSIFIED/UNLIMITED <input type="checkbox"/> SAME AS RPT <input type="checkbox"/> DTIC USERS		21 ABSTRACT SECURITY CLASSIFICATION <b>UNCLASSIFIED</b>	
22a NAME OF RESPONSIBLE INDIVIDUAL ADLER, R. W.		22b TELEPHONE (Include Area Code) 408-646-2352	22c OFFICE SYMBOL 62Ab

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Performance Evaluation of a Half-wave  
Resonant Slot Antenna over Perfect Ground  
Using NEC

by

Constantinos Theofanopoulos  
Lieutenant, Hellenic Navy  
B.S., Hellenic Naval Academy, 1978

Submitted in partial fulfillment of the  
requirements for the degree of

MASTER OF SCIENCE IN ELECTRICAL ENGINEERING

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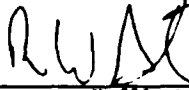
NAVAL POSTGRADUATE SCHOOL  
March 1987

Author:



Constantinos Theofanopoulos

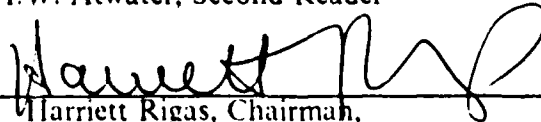
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## ABSTRACT

Present and future trends in shipboard antenna designs have as an objective, antennas which are or will be survivable in combat environments, integrable in ship's superstructures, low in profile and compact.

This thesis investigates the performance characteristics of a 7 by 0.2 meter slot antenna, which is cut into a rectangular bulkhead, the bulkhead being a section of the superstructure of an average ship. This slot antenna was modeled using the Numerical Electromagnetic Code. Input impedances, radiation patterns and near fields inside the slot are presented. The reason for conducting this performance evaluation is to determine if this approach to survivable antennas is feasible enough to be implemented in future ship designs.



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## ACKNOWLEDGEMENTS

I would like to express my thanks to Dr. Richard W. Adler, for his guidance and assistance in this study.

I would also like to dedicate this thesis to my wife Lydia and daughter Danae for their love, continuing support, understanding, patient help and cooperation throughout NPS.

Finally, I wish to thank all the Greek tax-payers, for having paid for my course of studies.

## I. INTRODUCTION

### A. NEED FOR THE STUDY

The choice of an antenna is an integral part of the design of an IIF communication system since the overall performance of the system greatly depends on the antenna performance.

Shipboard HF communication antennas, no matter how well designed and incorporated in an HF communication system, have certain drawbacks which must be seriously taken into account.

From the physical point of view antennas are inherently fragile structures and always protrude from a ship's silhouette, with the result that they are extremely vulnerable to man-made or natural threats.

From the tactical point of view, they increase the ship's profile and limit the firing zones of weapons systems.

Finally, examining electromagnetics, we realize that because of the limited space available aboard ships, the best type from the available classes of IIF antennas is not always used. Because of limited space, electrically small antennas must be used. Electrically small antennas are not necessarily physically small (for the lower part of the HF spectrum) and are narrowband structures. This implies that, in order to cover the whole HF spectrum, a large number of antennas must be used. Severe EMI problems can arise because of undesirable coupling between them and interference between links using these tightly coupled antennas.

All of these drawbacks can result in the loss of communication system effectiveness and consequently degrade the ship's fighting ability. Future ship designs will adopt more aerodynamical shapes with the consequent result of the elimination of tall and large superstructures. For these reasons, a study of methods, which can make communication antennas more survivable and integrable in the ship structure, is needed. One approach to solve this problem is to use integral parts of the ship as antennas. For example, sections of the ship's superstructure, the mast, the stack, etc. with proper excitation, might be used as antennas.

## **B. PROBLEM STATEMENT**

Adopting the above mentioned approach, that is the use of integral parts of the ship as antennas, this paper investigates the performance of a resonant halfwave slot antenna cut into a rectangular bulkhead, the bulkhead being a section of the superstructure of an average size ship.

The main purpose of this study is the development of an adequate computer model for the slot which will allow the evaluation of this antenna performance parameters and the comparison of computed results with theory. The computer code used to model this slot antenna is the Numerical Electromagnetic Code.

Since the bulkhead or the plane that contains the antenna is not infinite and rests on the main deck of a vessel, some differences between theoretical and computed impedance values are expected.

Section D is devoted to the theory of slot antennas from classical texts in the field of antennas. Chapter II has the model description. Chapter III discusses the results of the simulation and compares the computed values to theoretical values. Chapter IV comments on the feasibility of the application of such antennas in the real world. Appendix A is a brief description of NEC and its methods and limitations in performing the electromagnetic analysis.

## **C. CORRESPONDENCE**

At the beginning of this study, about 90 letters were addressed to major foreign (non-USA) antenna manufacturers and leading shipbuilding industries requesting information about their involvement in projects of of this type.

Answers are still coming and can be summarized in three categories.

- They are not interested in this kind of research.
- They would like to see the results of this and previous research on this subject.
- They have done similar research but it is up to their Department of Defence to share the results with us.

A letter we received recently, demonstrates a work done by the "DIRECTIONS DES CONSTRUCTION ET ARMES NAVALES DE TOULON" under the object title "ANTENNES DE STRUCTURE". The code name of the experiment was CERTEL and was conducted in 1978 onboard a destroyer escort of the AVISO 69 class.

Similar work was conducted by the Dutch Department of Defence and the British Admiralty, but no details could be provided.

## D. SLOT ANTENNA THEORY

### 1. Aperture or Displacement Current Antennas

For the majority of antennas that operate at UHF and microwave frequencies, the "source" of radiation is the electromagnetic field at the antenna aperture or the antenna surface. An example of an aperture antenna is the slot antenna where an electromagnetic field is coupled to the radiating surface of the aperture by use of a transmission line from the transmitter. Fig 1.1 shows a slot antenna.

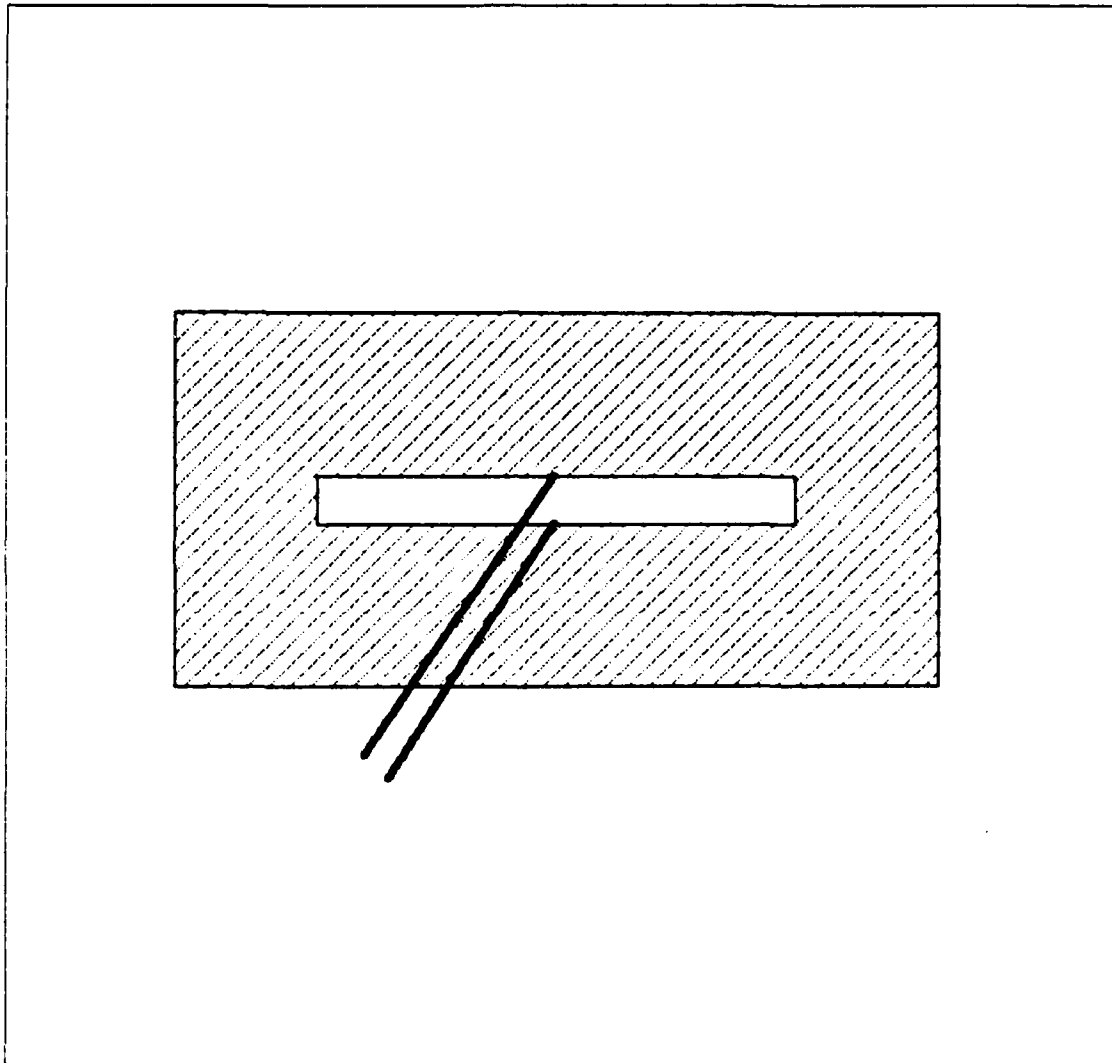


Figure 1.1 Slot Antenna.

An important feature of slot antennas, and in general of aperture antennas, is that there is no conduction current at the radiator surface, although surrounding metallic environments will support conduction currents.

Huygen's principle, a well known principle from optics, can be used in order to obtain the radiation intensity from antennas where electromagnetic fields act as sources. It states: "If the fields are known at a time  $t$ , fields everywhere at a later time can be obtained by considering the known fields of time  $t$ , as Maxwell 'sources' of waves that add to produce fields everywhere".

Thus a prescribed or assumed field distribution at a radiating surface (or an aperture) can be used to calculate the fields elsewhere from Maxwell's equations.

The most commonly used approach for such calculations, was developed by Schelkunoff, and it is known as the Schelkunoff equivalence principle. It is derived from Maxwell's equations and states: "Electromagnetic fields in space, due to sources at a radiating surface, can be calculated by defining electric and magnetic surface currents on the radiating surface, mathematically equivalent to tangential magnetic and electric fields at the radiating surface respectively". [Ref. 1: pages 127-28]

## **2. Rectangular Slots and Their Radiation Patterns**

A simple example of a slot antenna consists of a rectangular slot cut in an extended, thin, flat metal sheet with the slot free to radiate on both sides of this sheet as shown in Fig. 1.1

Such slots may be excited by a voltage source, such as a balanced parallel transmission line connected to the opposite edges of the slot, by a transmission line connected across the slot, as in this study case, or by means of an energized cavity placed behind it, or by using a waveguide. Transmission lines are used at UHF frequencies, and cavities and waveguides at microwave frequencies. Figure 1.2 shows how a slot is fed by a coaxial transmission line.

In order to derive the radiation patterns of a slot, another well known principle from optics, the Babinet's principle, is used, which in general states: "A slot has identical radiation patterns to that of a complementary dipole which could just fit the slot opening; the only difference is that the orientations of the Electric and Magnetic fields are interchangeable in the two cases". Fig 1.3 shows the basic radiation patterns for a slot antenna.



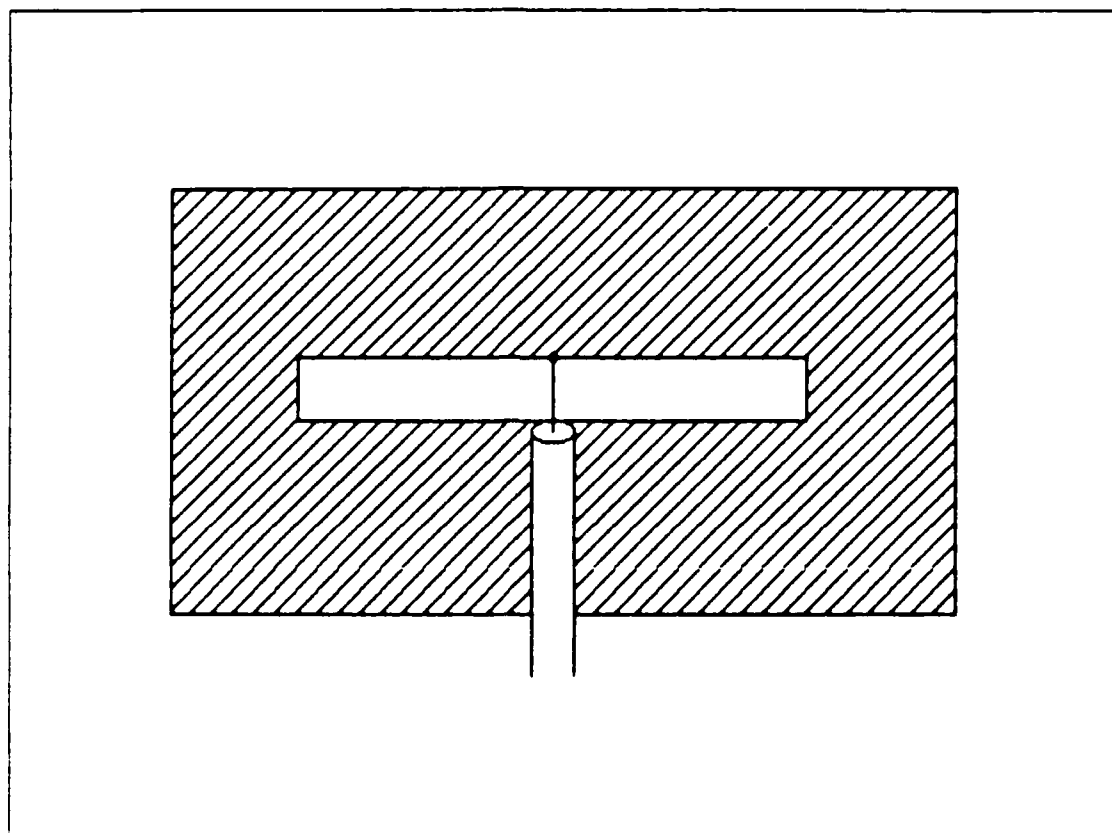


Figure 1.2 Slot Antenna Fed by a Coaxial Transmission Line.

### 3. Slot Impedances

The impedance of a slot antenna in a flat metal sheet, which is free to radiate on both sides, can be obtained directly from the impedance of the complementary wire antenna using Babinet's principle.

The equation that gives this result is Equation 1.1

$$Z_{\text{slot}} Z_{\text{dipole}} = Z_0^2 / 4 \quad (\text{eqn 1.1})$$

or

$$Z_{\text{slot}} = Z_0^2 / 4 Z_{\text{dipole}} \quad (\text{eqn 1.2})$$

Equation 1.2 states that the terminal impedance  $Z_{\text{slot}}$  of a slot antenna is equal to  $1/4$  of the square of the intrinsic impedance  $Z_0$  of the surrounding medium divided by  $Z_{\text{dipole}}$  the terminal impedance of the complementary dipole.

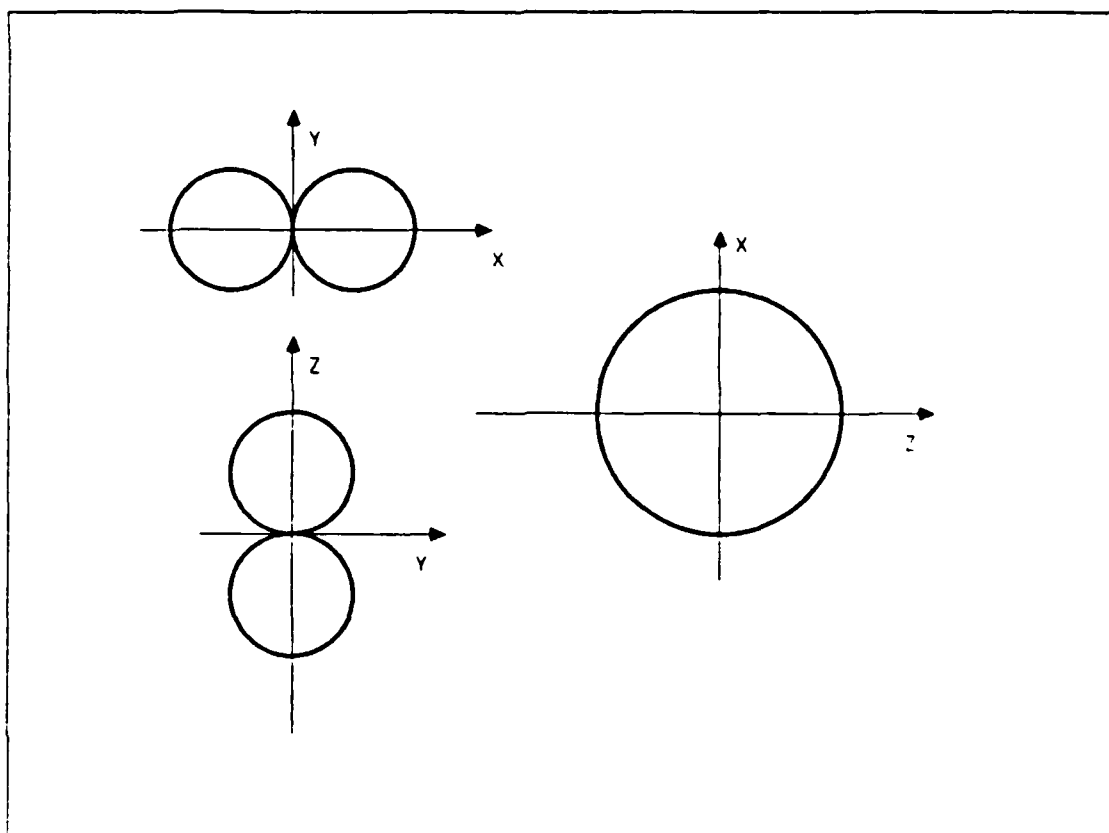


Figure 1.3 Basic Radiation Patterns of a Slot Antenna.

It can be easily shown that for inductive dipoles, the corresponding complementary slot is capacitive. Also the impedance of the slot is proportional to the admittance of the dipole or vice versa, and lengthening a slot makes it more inductive.

The above discussion applies to slots in sheets of infinite extent. If the metal is finite, the impedance values are substantially same. [Ref. 2: p. 345]

#### 4. Boxed-in or Cavity-backed Slot Antennas

As mentioned previously, a half-wavelength slot antenna cut into a rectangular metal sheet radiates equally on both sides of the sheet and its radiation patterns are identical to those of the complementary dipole.

In order to make the radiation pattern unidirectional, the boxed-in antenna shown in Figure 1.4 may be used.

If the depth  $d$  of the box is equal to  $\lambda/4$  two things happen. First, the radiation sent in the back direction undergoes a  $180^\circ$  phase shift upon reflection at the back metallic wall of the box and a  $180^\circ$  phase shift going and returning for a total distance  $2d = \lambda/2$ . This results in a phase coherent addition on the front side meaning 16 times as much radiation intensity on the front side as that of a simple slot antenna radiating bidirectionally. A 4 times improvement in the radiation intensity for half the volume means a two-fold improvement in the radiated power. [Ref. 1: p. 152].

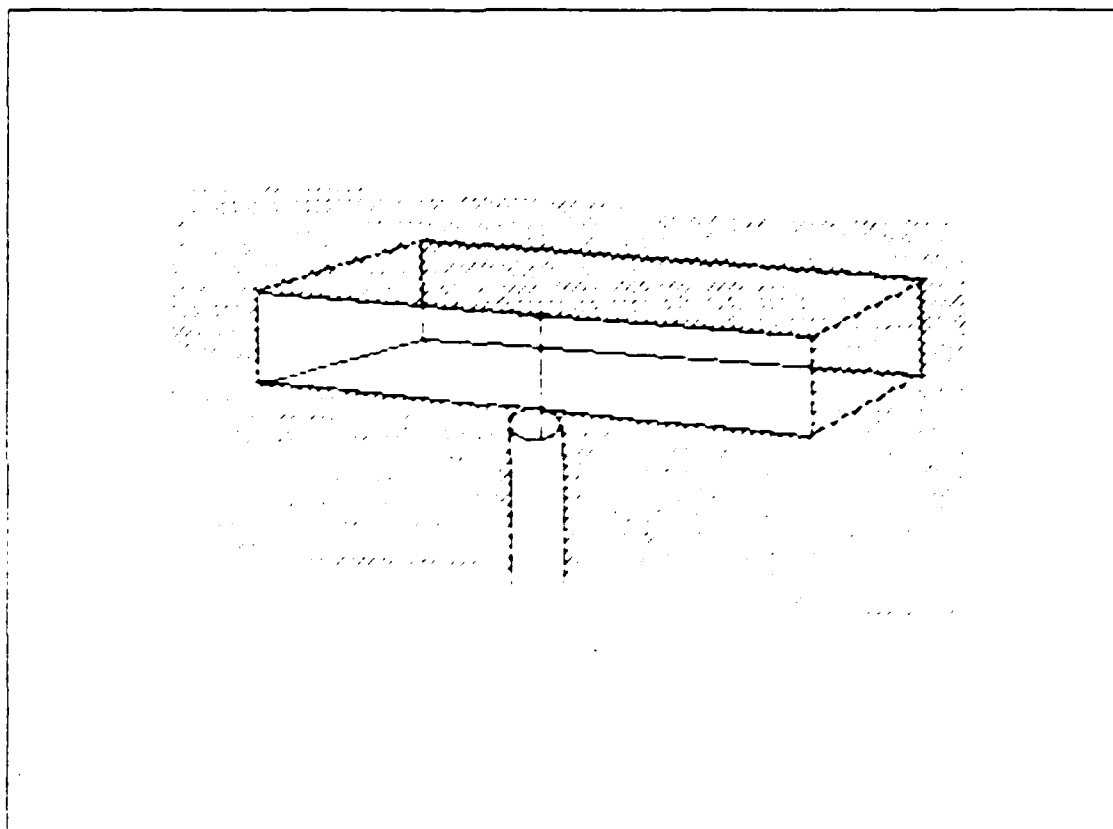


Figure 1.4 Cavity-backed Slot Antenna.

And secondly, no appreciable shunt susceptance appears across the terminals. With such a zero susceptance box, the terminal impedance of the resonant half-wavelength slot is non-reactive and approximately twice its value without the box or about 1000 Ohms.

In other words, the electric field along the cavity-backed rectangular slot of Figure 1.4 is not necessarily sinusoidal or related to a complementary wire antenna. The boxed-slot antenna can be treated as a cavity resonator, which is energized by some transducer and free to radiate out of the slot. The field distribution in the slot, therefore, is dependent on the relative excitation of the principal and higher order modes.

The equivalent circuit of a cavity antenna is shown in Figure 1.5. The shunt conductance is the radiation conductance for the given distribution. In the case of the resonant half-wavelength slot, the conductance is halved by the presence of the cavity, since the slot radiates only in to half space so that the shunt resistance is approximately 800 to 1000 Ohms.

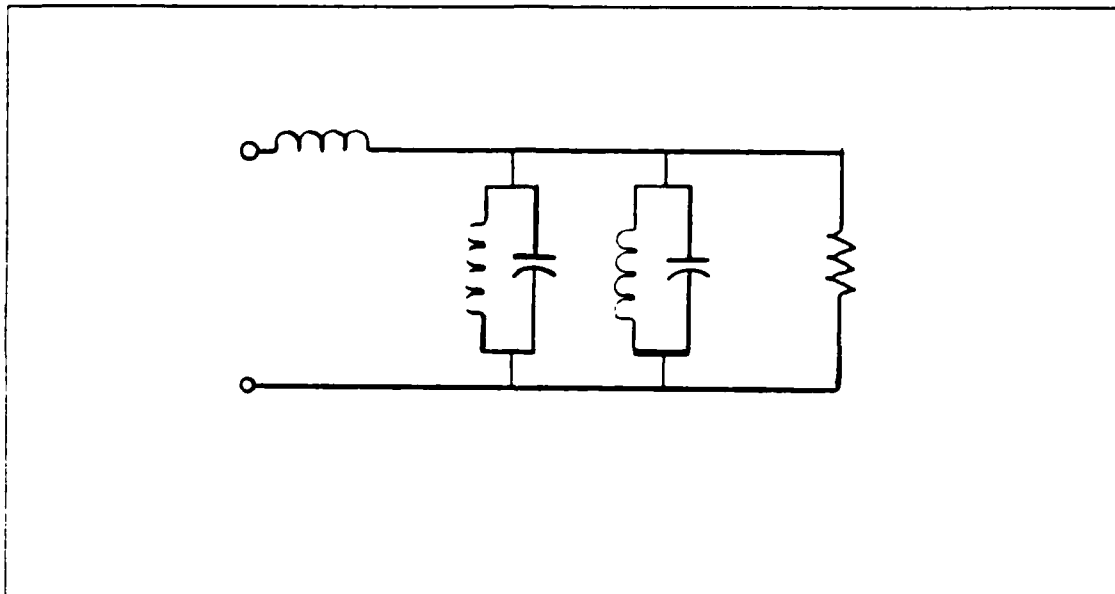


Figure 1.5 Equivalent Circuit of a Cavity-backed Slot Antenna.

The parallel susceptance is the sum of the shunt susceptance of the slot and the TE-mode susceptance of the cavity.

The series-resonant circuit is the result of the energy stored in the TM modes in the the cavity and feed structure. Alternatively, the energy stored in the shunt circuit and the energy stored in the series circuit corresponds to the stored energy in the TE and TM modes respectively. [Ref. 3: p. 8-13]

## II. MODEL DESCRIPTION

The antenna structure that will be modeled and examined by this thesis is a rectangular slot antenna cut into a rectangular conducting metal sheet. This antenna structure simulates a bulkhead of an average size ship with a rectangular slot cut into it. Figure 2.1 shows the model of the bulkhead with the slot.

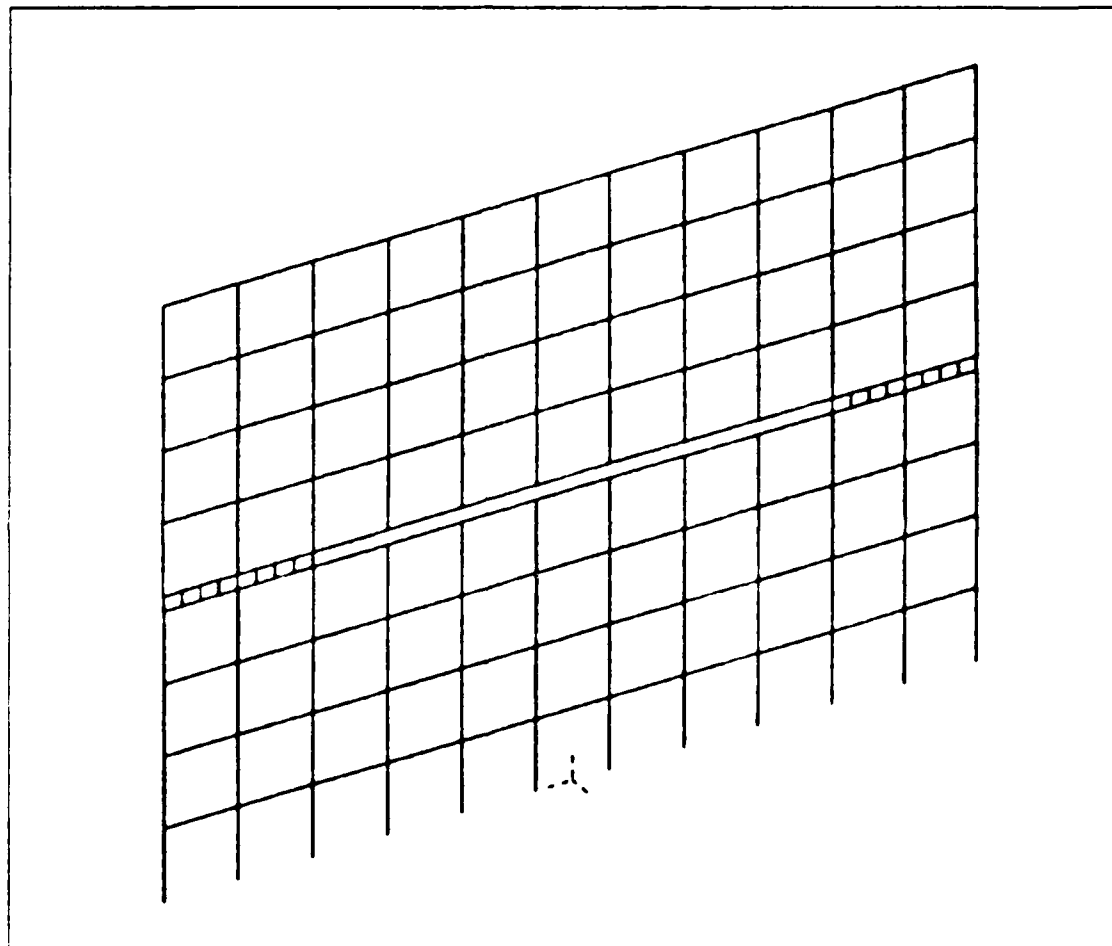


Figure 2.1 Bulkhead with Slot Antenna.

Applying the wire grid surface option of the Numerical Electromagnetic Code, with the proper use of the geometry card family GW, GM, GX and GE, this antenna structure (conducting metal sheet and slot), when modeled is replaced by a wire mesh

or grid. Figure 2.2 shows the listing of the NEC geometry cards that created the model.

```

CM BASIC MODEL
CM 11 BY 8.2
CE RUN FOR NGF
GW 1,1,-5.5,0,8.2,-4.5,0,8.2,.01
GW 2,1,-5.5,0,8.2,-5.5,0,7.2,.01
GW 3,1,-5.5,0,7.2,-4.5,0,7.2,.01
GW 4,2,-5.5,0,7.2,-5.5,0,6.2,.01
GW 5,2,-5.5,0,6.2,-4.5,0,6.2,.01
GW 6,2,-5.5,0,6.2,-5.5,0,5.2,.01
GW 7,4,-5.5,0,5.2,-4.5,0,5.2,.01
GW 8,4,-5.5,0,5.2,-5.5,0,4.2,.01
GW 9,8,-5.5,0,4.2,-4.5,0,4.2,.01
GW 10,8,-5.5,0,4,-4.5,0,4,.01
GW 11,4,-5.5,0,4,-5.5,0,3,.01
GW 12,4,-5.5,0,3,-4.5,0,3,.01
GW 13,2,-5.5,0,3,-5.5,0,2,.01
GW 14,2,-5.5,0,2,-4.5,0,2,.01
GW 15,2,-5.5,0,2,-5.5,0,1,.01
GW 16,1,-5.5,0,1,-4.5,0,1,.01
GW 17,1,-5.5,0,1,-5.5,0,0,.01
GM 17,4,0,0,0,1,0,0,1.17
GW 86,1,-5.5,0,4.2,-5.5,0,4,.01
GM 1,8,0,0,0,.25,0,0,86
GW 95,1,0,0,8.2,-5.5,0,8.2,.01
GW 96,1,-5.5,0,8.2,-5.5,0,7.2,.01
GW 97,1,0,0,7.2,-5.5,0,7.2,.01
GW 98,2,-5.5,0,7.2,-5.5,0,6.2,.01
GW 99,1,0,0,6.2,-5.5,0,6.2,.01
GW 100,2,-5.5,0,6.2,-5.5,0,5.2,.01
GW 101,2,0,0,5.2,-5.5,0,5.2,.01
GW 102,4,-5.5,0,5.2,-5.5,0,4.2,.01
GW 103,4,0,0,4.2,-5.5,0,4.2,.01
GW 104,4,0,0,4,-5.5,0,4,.01
GW 105,4,-5.5,0,4,-5.5,0,3,.01
GW 106,2,0,0,3,-5.5,0,3,.01
GW 107,2,-5.5,0,3,-5.5,0,2,.01
GW 108,1,0,0,2,-5.5,0,2,.01
GW 109,2,-5.5,0,2,-5.5,0,1,.01
GW 110,1,0,0,1,-5.5,0,1,.01
GW 111,1,-5.5,0,1,-5.5,0,0,.01
GX 111,100
CE 1
GN 1
FR 0,0,0,0,20.357
WG
XQ
EN

```

Figure 2.2 Listing of NEC Cards that Created the Model.

Various models for this structure were created, the criterion of selecting the final model having been determined by NEC modeling guidelines and limitations, by computer storage and running time and by the calculated "average gain" of each model.

The final model is a wire grid of dimensions 11 by 8.2 meters with an opening at its center of 7 by 0.2 meters. This model was created using guidelines from [Ref. 4].

Since a ship is a large, complex conducting body, the performance of any antenna will be significantly modified by the vehicle on which it is mounted. An antenna fed against an upper deck is, in effect, a grounded antenna with an elevated feed, but the lower part of the antenna, the body of the ship, is physically large in terms of wavelengths. The "ground" is the ocean on which the ship is floating and is a good conducting medium. Therefore this model was run over perfect ground. [Ref. 5: p 2-9].

In building this model, segments of different sizes were utilized. The model has smaller segments near its center, where the slot is located. Also, the number of segments was progressively increased from the edges of the bulkhead to the area near the slot, because the paths of the currents near the slot area are critical in the development of the requested performance parameters.

The total number of segments used is 578. The model was first run at the frequency of 20.357 Mhz, the resonant frequency of the slot.

The antenna was excited using a voltage source across the center of the slot ( $x=0$ ) and then at six different points along the horizontal axis from  $x=0.5$  to  $x=3$  meters (at  $x=0.5, 1, 1.5, 2, 2.5, 3$  meters).

Requested output data were the antenna's terminal impedance and radiation patterns, the main characteristics describing antenna performance. For the slot antenna, the terminal impedance is the impedance seen by the voltage source which excites the antenna. This impedance is required for matching the antenna to a transmission line which connects to a transmitter or receiver. The radiation patterns of an antenna define its directionality and gain characteristics, hence communication system effectiveness.

Many data sets were created to study the performance characteristics of the antenna with frequency variation (bandwidth performance) at frequencies of 5, 10, 15, 18, 19, 21, 22, 25 and 30 Mhz.

A double precision module, DNPS1000, of the NEC FORTRAN family was used for this evaluation. In performing these calculations, both the time-share CMS and batch, MVS operating systems of the NPS IBM 3033S mainframe computer were used.

### III. NUMERICAL RESULTS

#### A. INPUT IMPEDANCES

For a slot antenna, the input or terminal impedance is the impedance seen by the voltage source used to excite the antenna. The knowledge of its value is important when trying to match the antenna to a transmission line, for efficient power transfer. Figures 3.1 and 3.2 shows the resistance and reactance of this slot antenna as functions of the feeding point location along the horizontal axis for seven different locations. Table 1 shows the values which were plotted.

TABLE I  
INPUT IMPEDANCES ALONG X-AXIS

Distance from origin (m)	Input impedances (ohms)		
0.0	443.8	-	337.2j
0.5	393.5	-	297.0j
1.0	368.8	-	248.9j
1.5	265.1	-	151.3j
2.0	191.4	-	58.6j
2.5	92.7	+	12.9j
3.0	30.4	+	54.8j

As shown in Figures 3.1 and 3.2, resonance occurs at  $x = 2.45$  m where the value of the resistance is 110 Ohms. An input impedance of 50 ohms occurs at  $x = 2.85$  m and of 75 Ohms at  $x = 2.70$  m.

As is the case with slot antennas in sheets of infinite extent, it is proven here that an off-center feed is required to match the slot to the standard 50 and 75 Ohm coaxial lines.



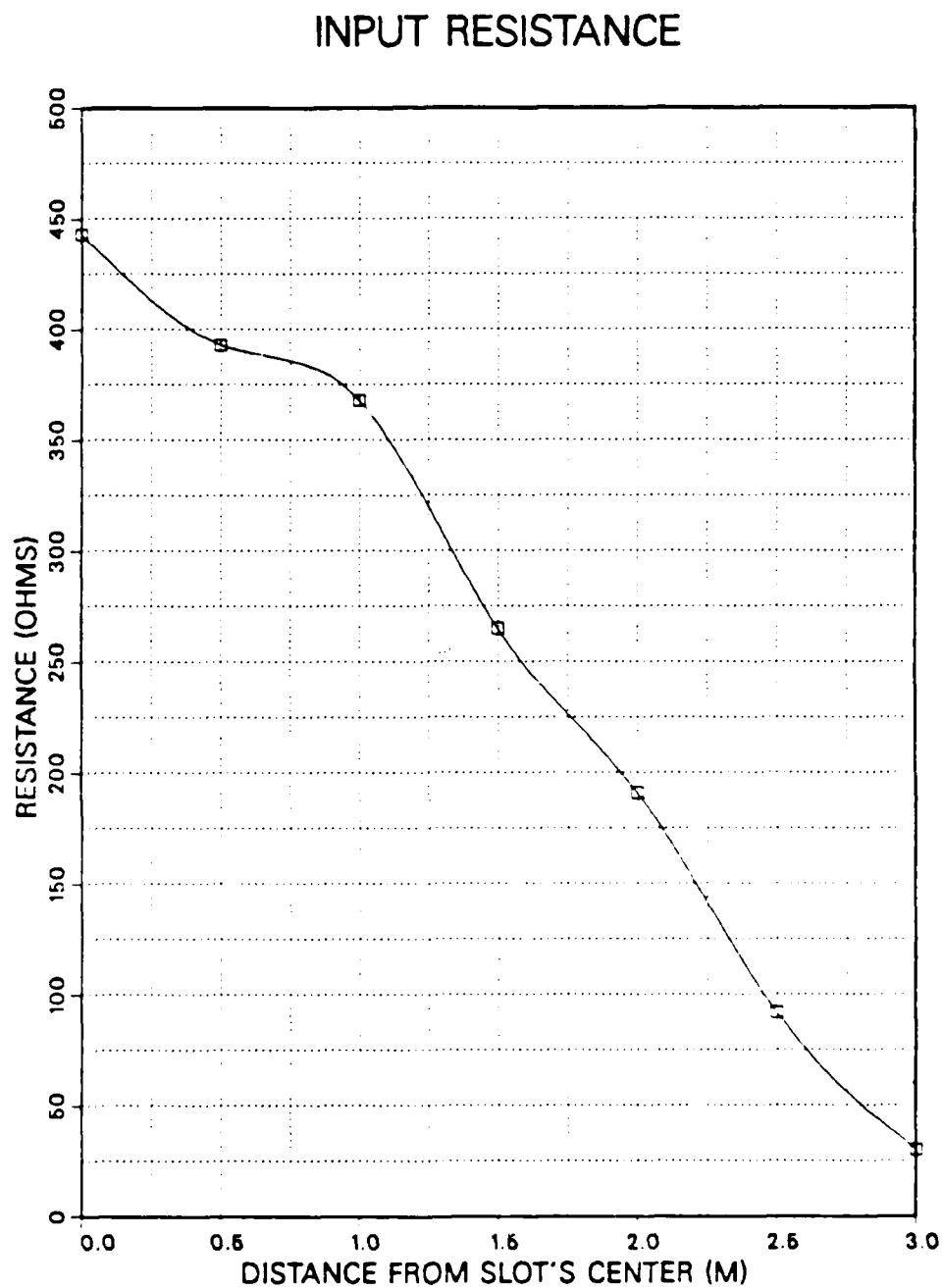


Figure 3.1 Input Resistance at 20.357 Mhz.

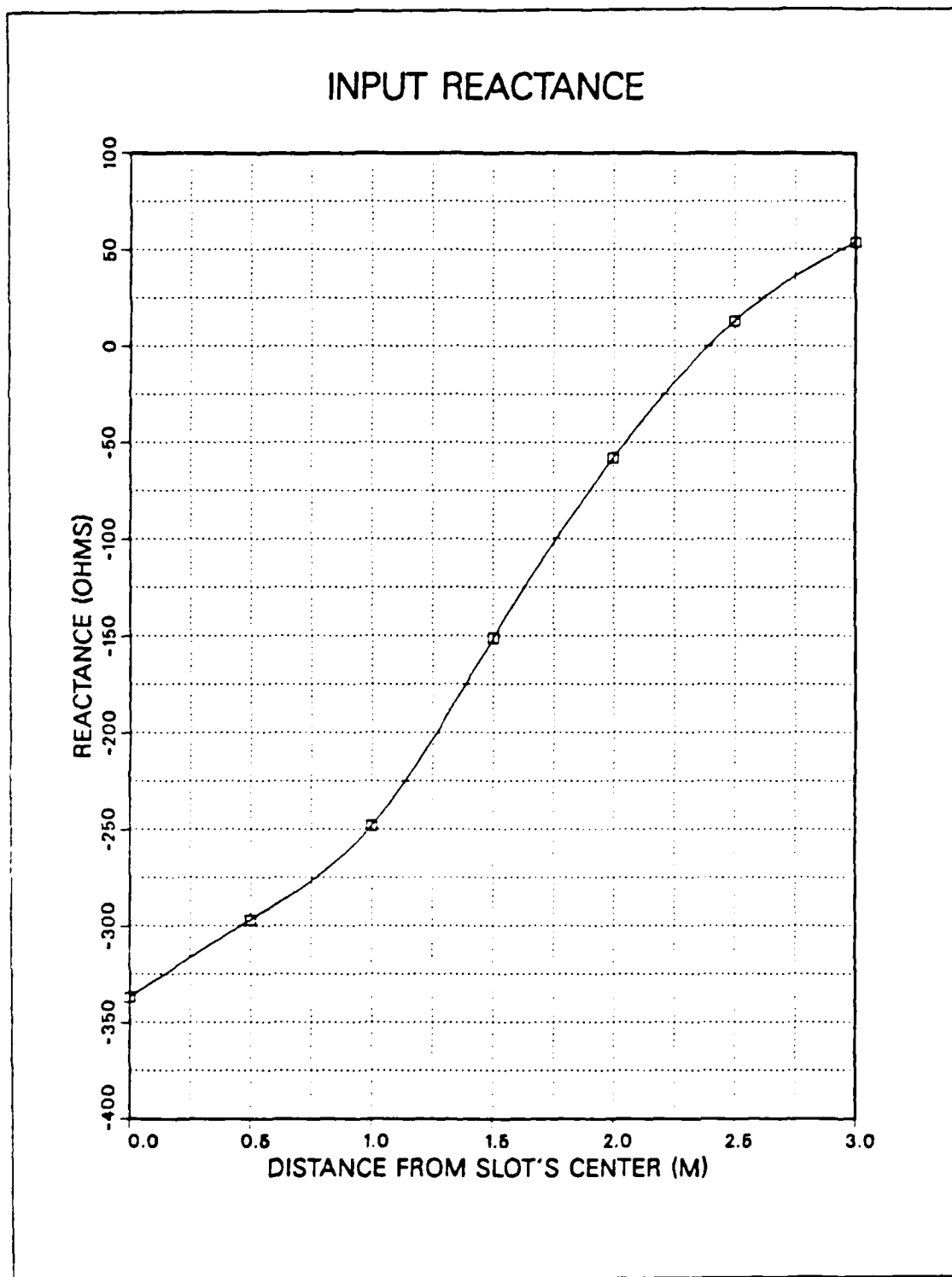


Figure 3.2 Input Reactance at 20.357 Mhz.

## B. FREQUENCY PERFORMANCE

Keeping the feed point location ( $x=0$  m) fixed, the variation of the input impedance is examined for 18 to 22 Mhz in steps of 1 Mhz (Table 2)

TABLE 2	
FREQUENCY PERFORMANCE 18 TO 22 MHZ	
Frequency (Mhz)	Input Impedances (Ohms)
18	605.5 + 613.5j
19	1010.2 + 56.0j
20	571.2 - 346.7j
21	303.1 - 280.5j
22	204.5 - 192.2j

The values from Table 2 are plotted in Figure 3.3. It is apparent that resonance is near 19 Mhz. Figure 3.4 shows the input impedance variation with frequency from 5 to 30 Mhz.

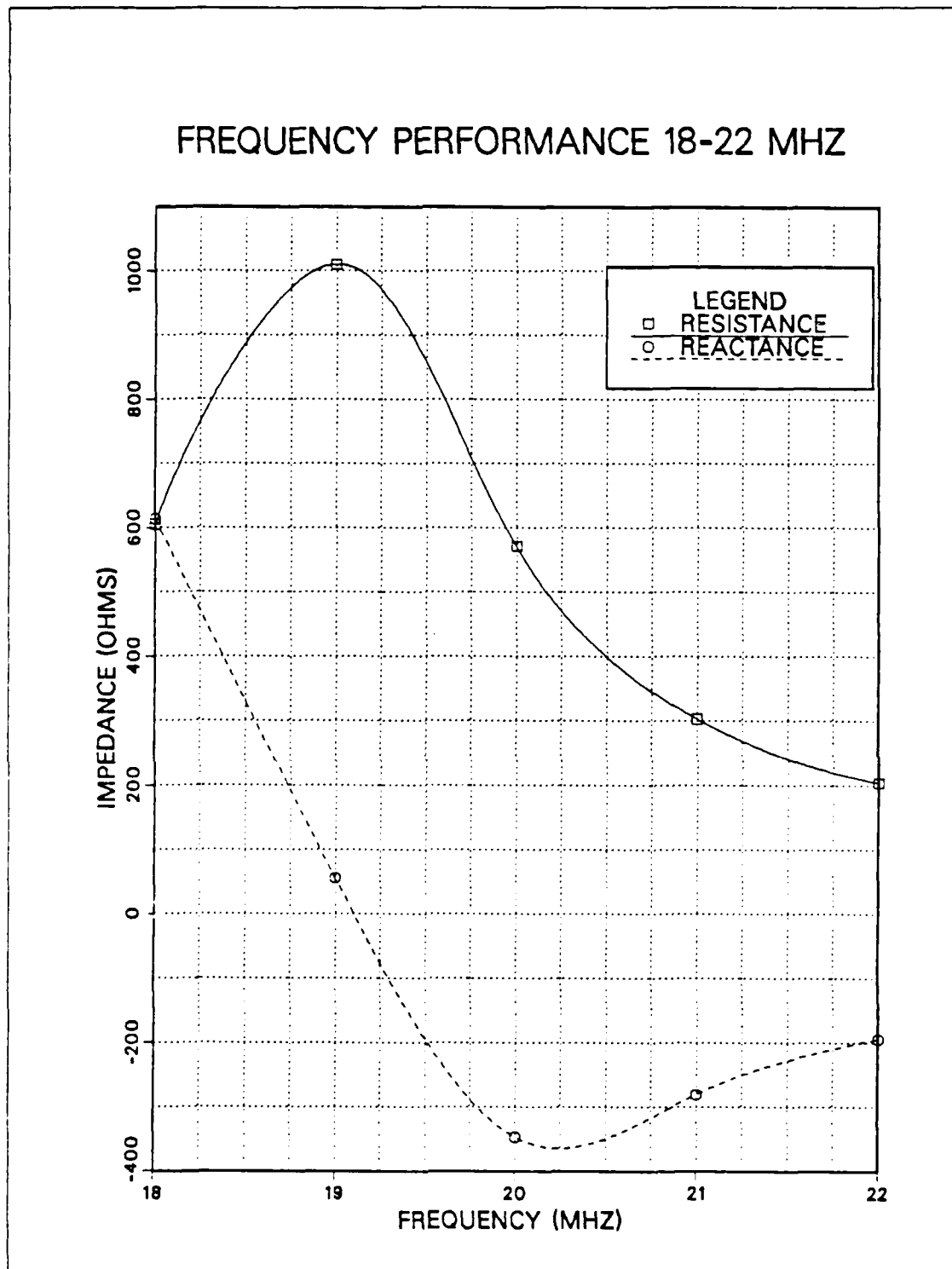


Figure 3.3 Frequency performance 18 to 22 Mhz.

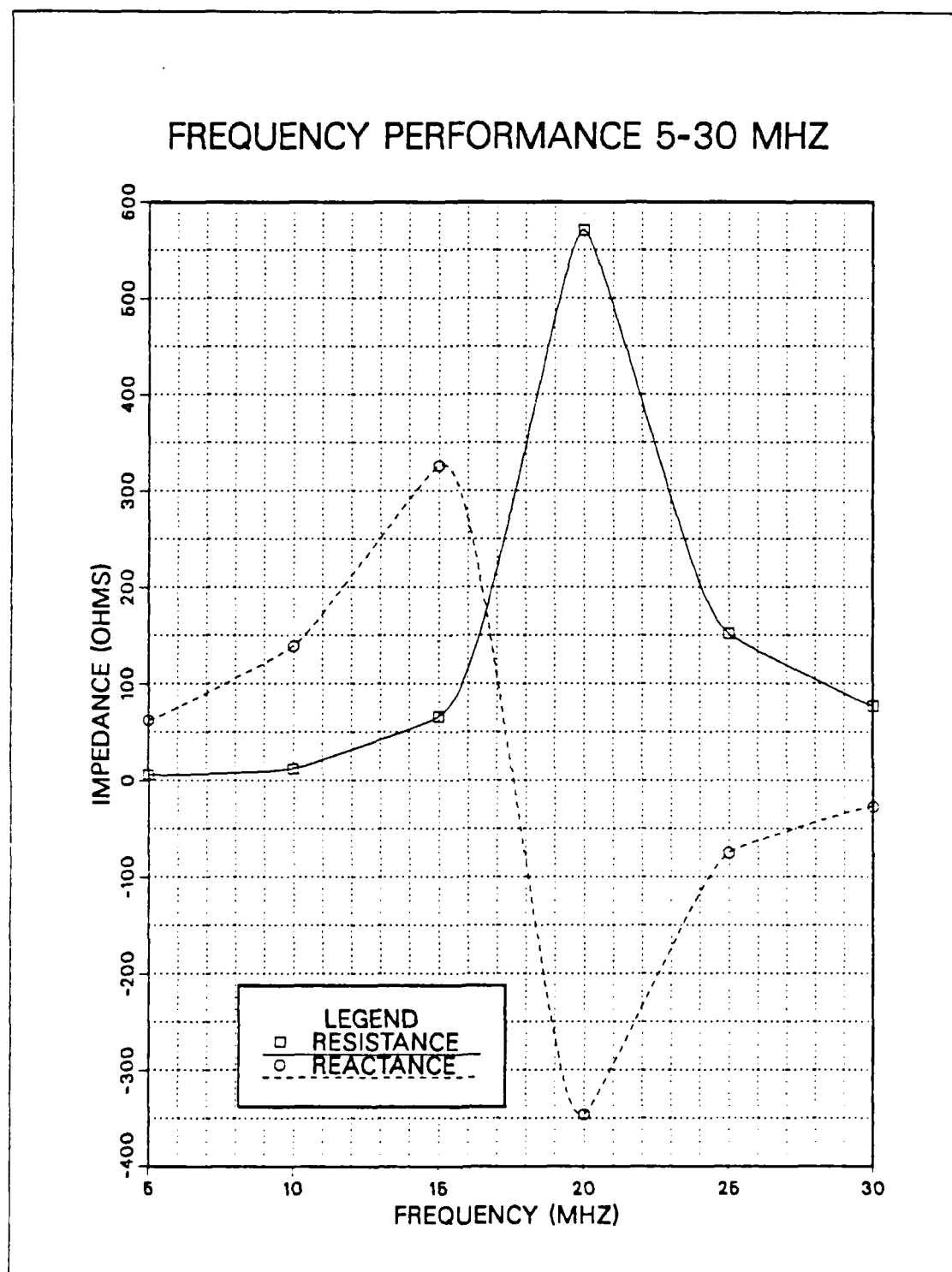


Figure 3.4 Frequency performance 5 to 30 Mhz.

### C. RADIATION PATTERNS

As mentioned previously the radiation patterns of an antenna define its directionality and gain characteristics.

Figures 3.5 to 3.14 are a set of radiation patterns of the slot antenna model at a frequency of 20.357 Mhz for various azimuth and elevation angles.

Comparing the obtained radiation patterns of the modeled slot to those of a reference dipole, the slot gives almost omnidirectional coverage, (no nulls) and the maximum intensity is about 3db better than that of the dipole.

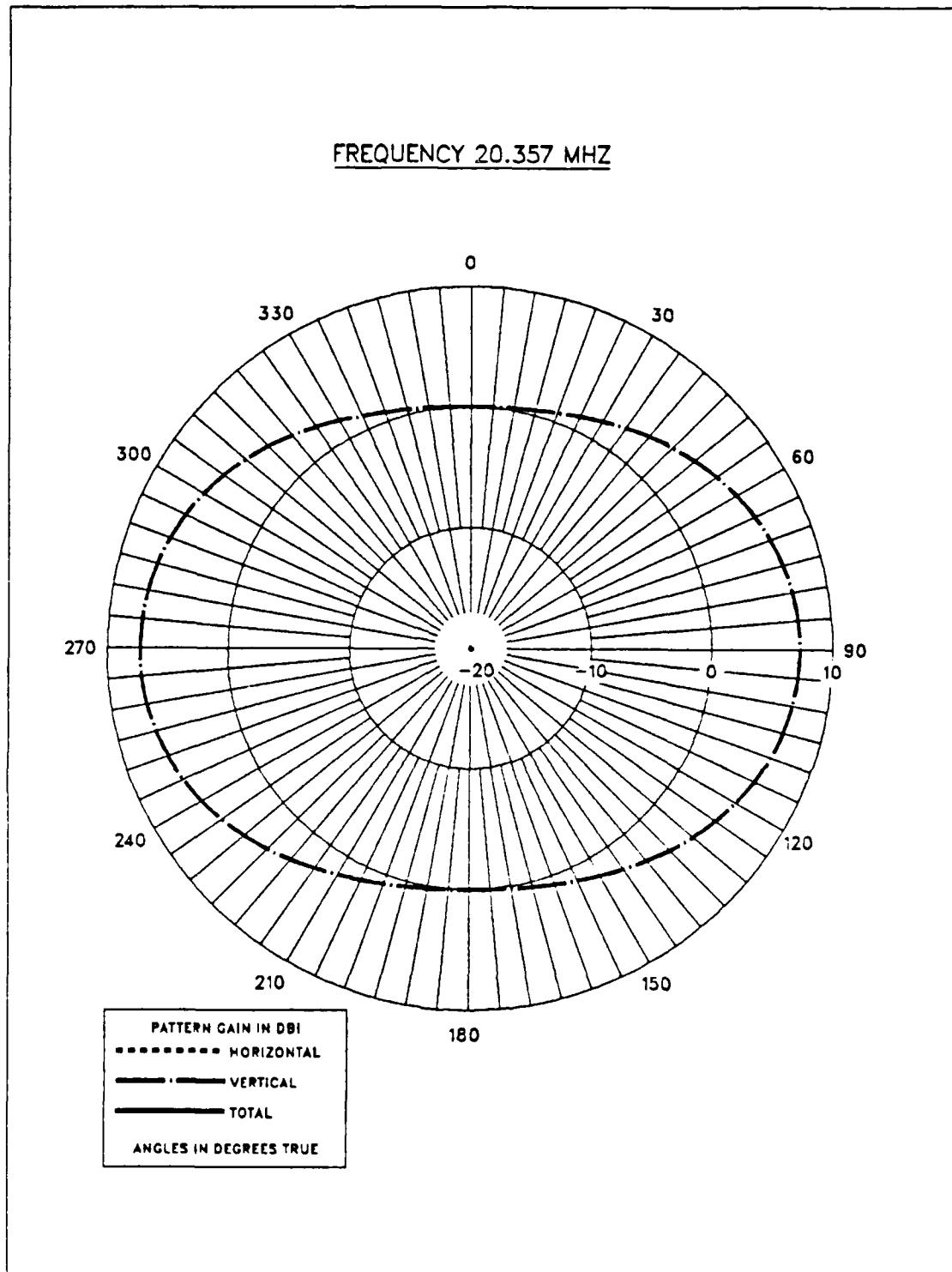


Figure 3.5 Azimuth Pattern at 0° Elevation.

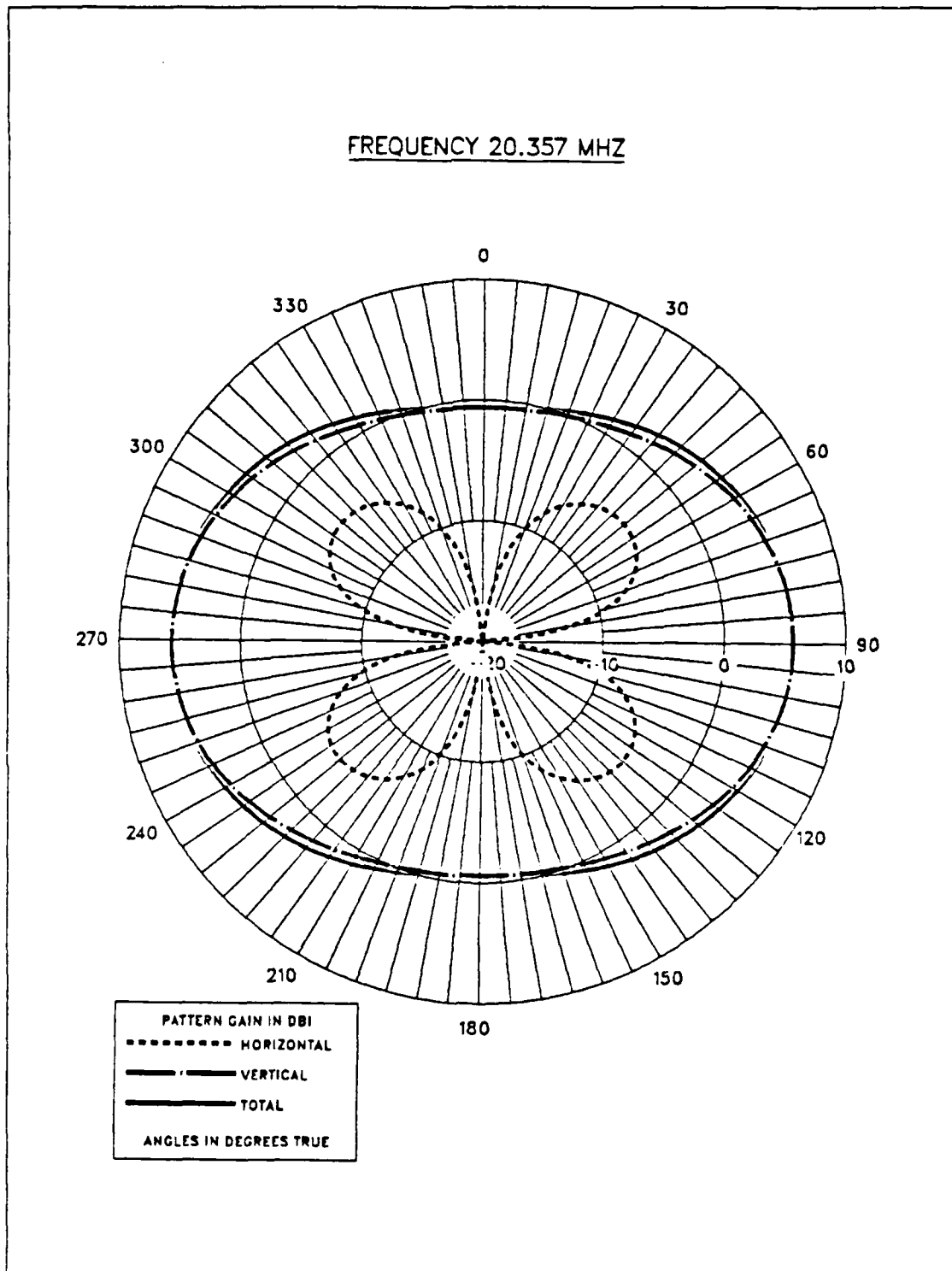


Figure 3.6 Azimuth Pattern at 15° Elevation.



FREQUENCY 20.357 MHZ

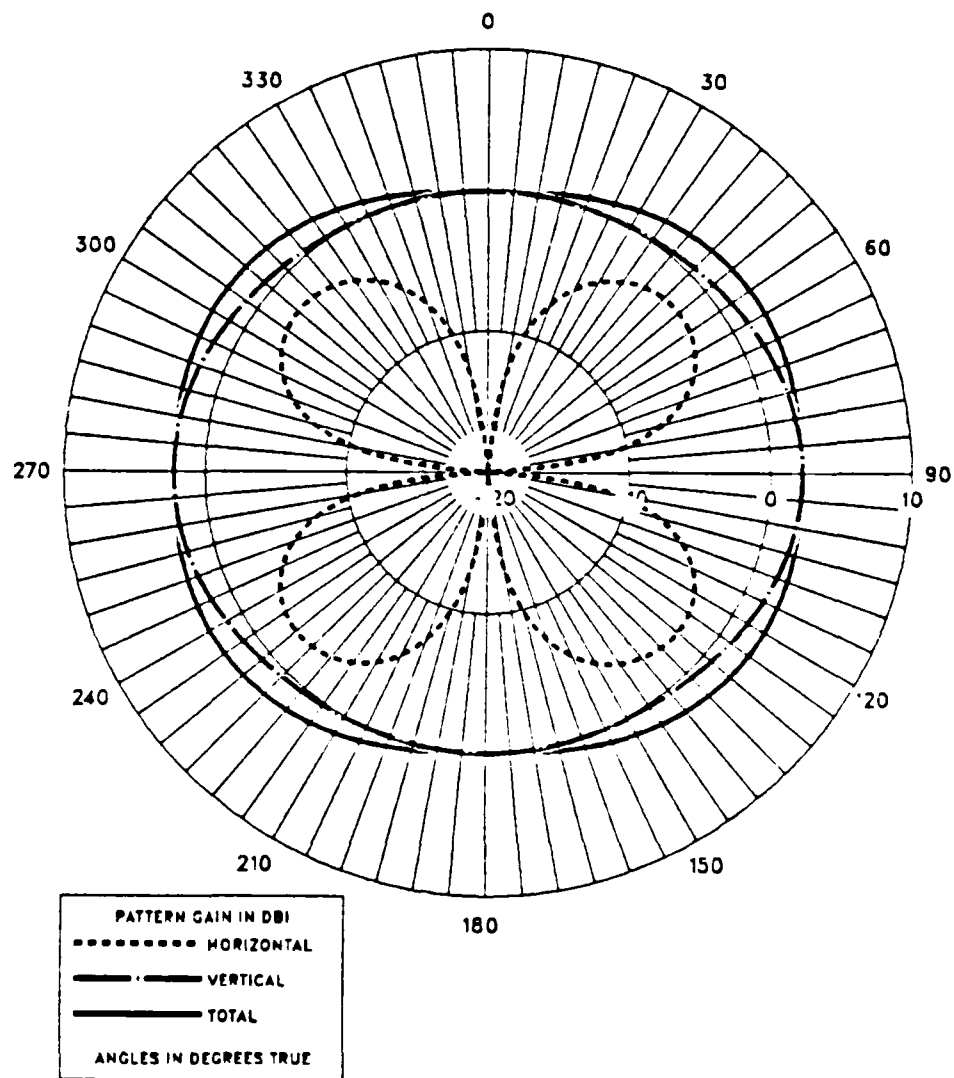


Figure 3.7 Azimuth Pattern at 30° Elevation.

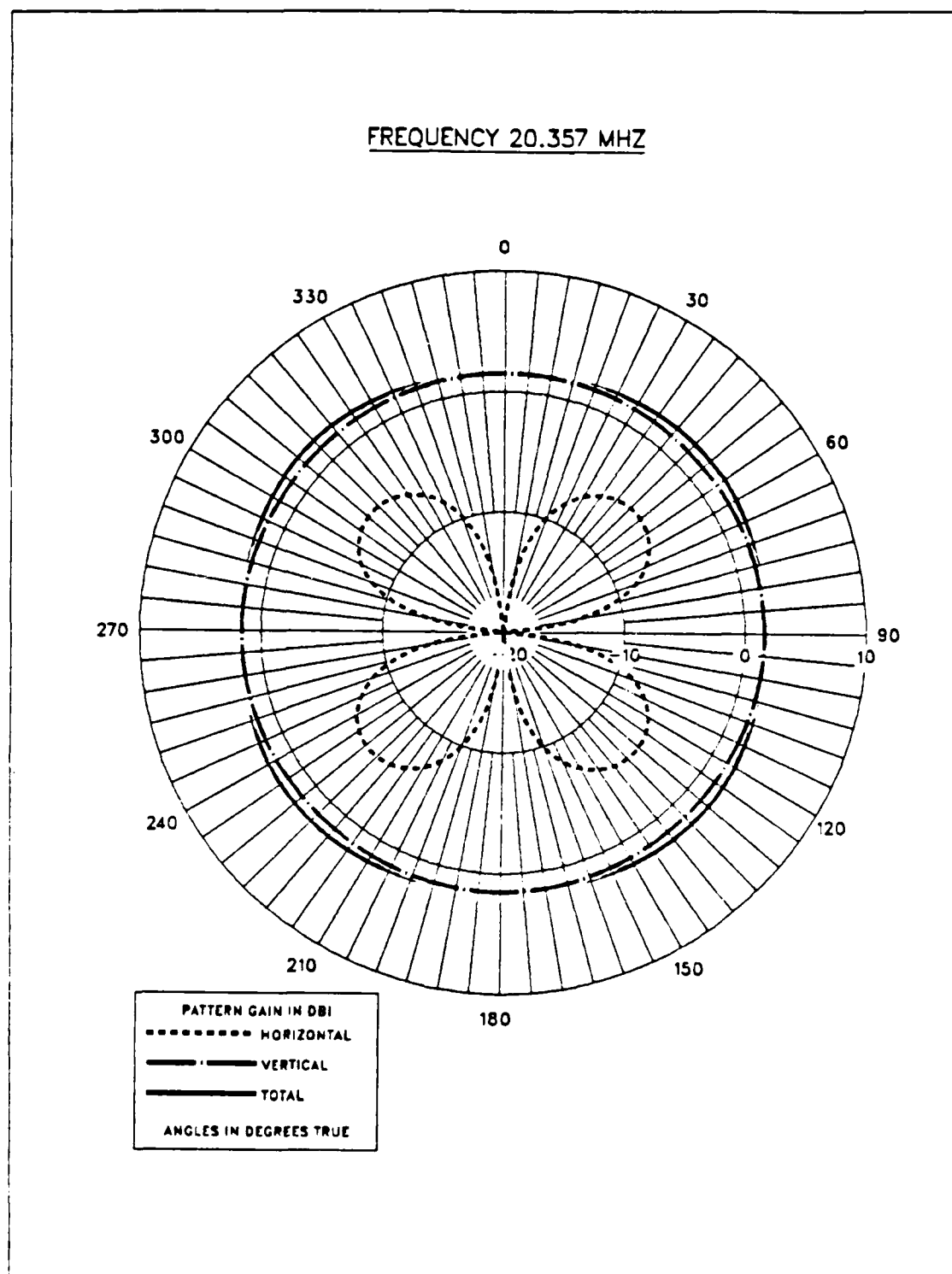


Figure 3.8 Azimuth Pattern at 45° Elevation.

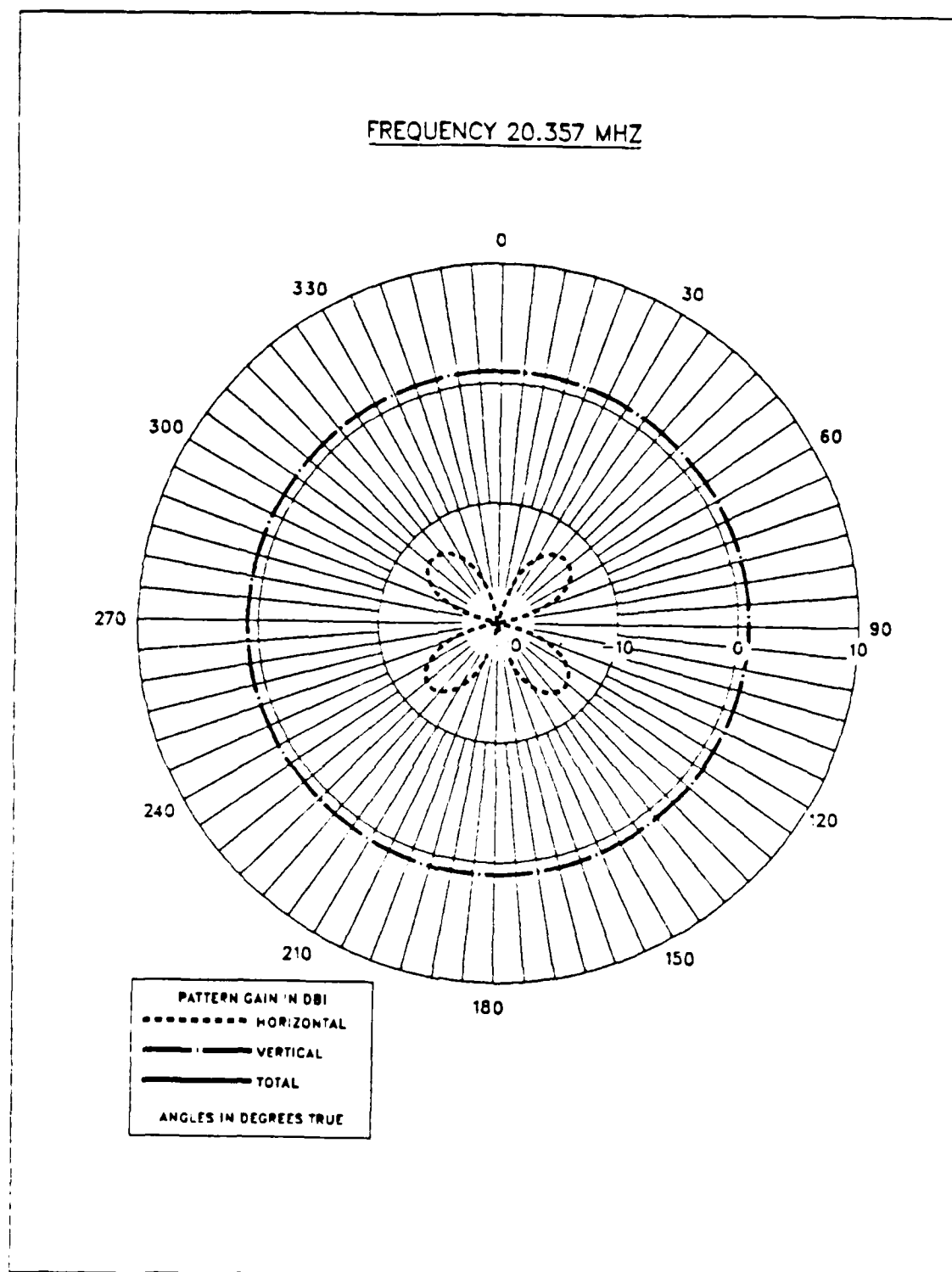


Figure 3.9 Azimuth Pattern at 60° Elevation.

FREQUENCY 20.357 MHZ

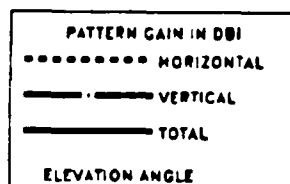
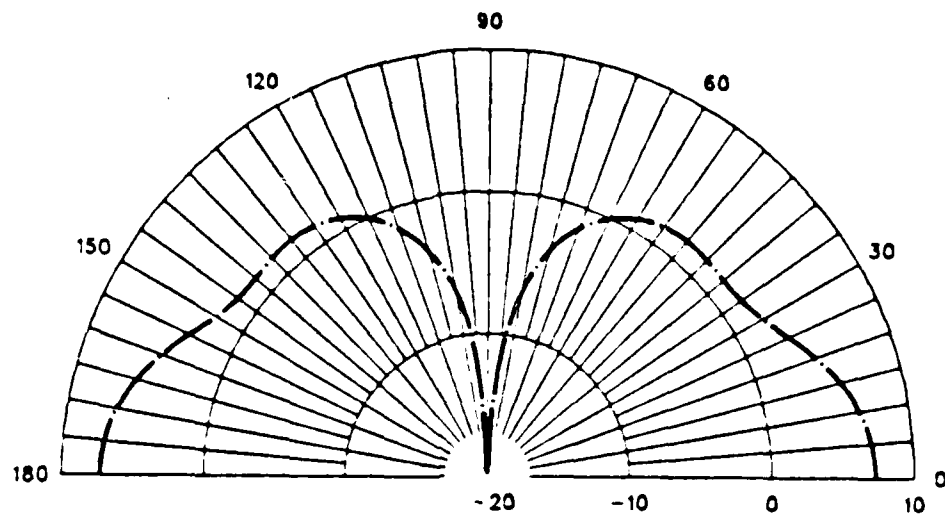


Figure 3.10 Elevation Pattern at 90° Azimuth.

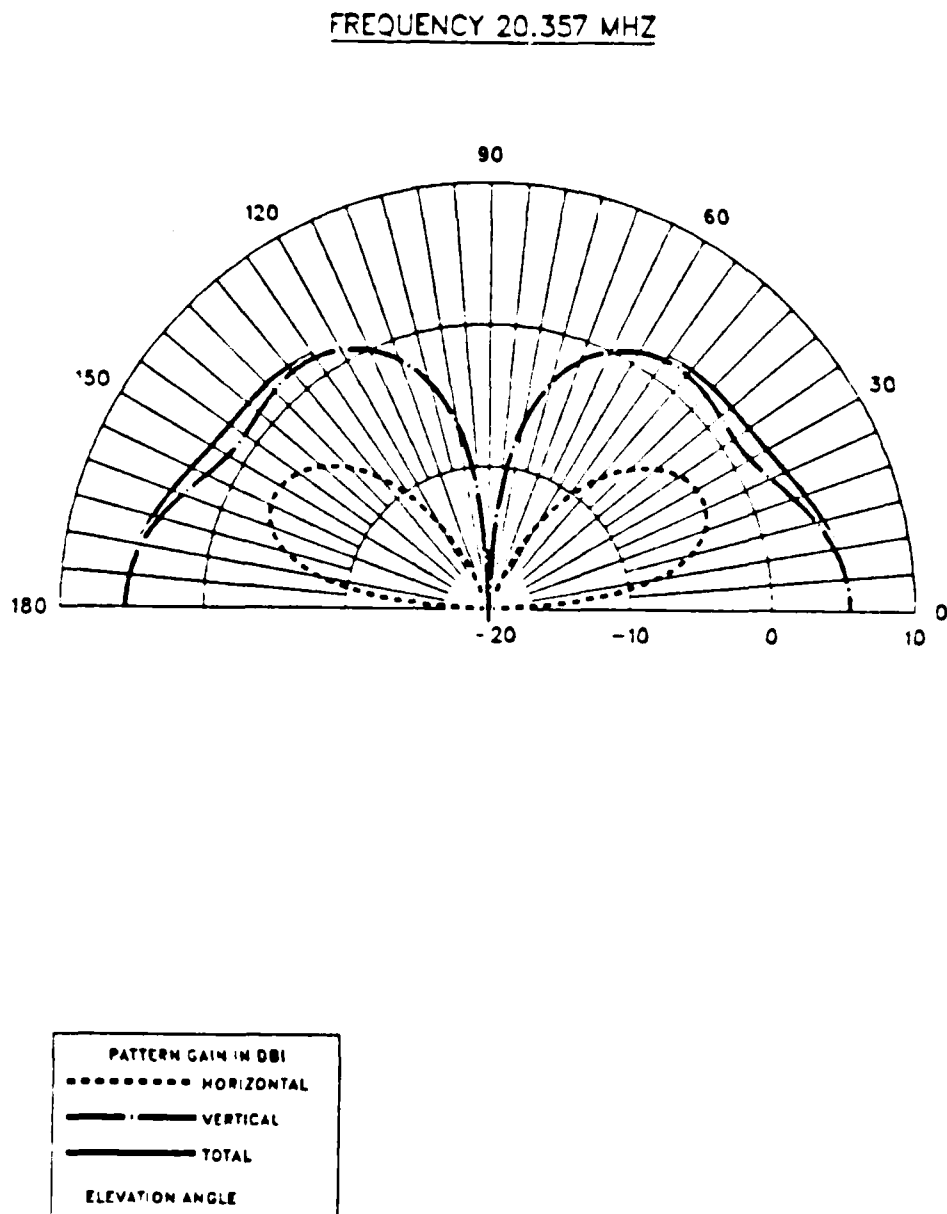


Figure 3.11 Elevation Pattern at 60° Azimuth.

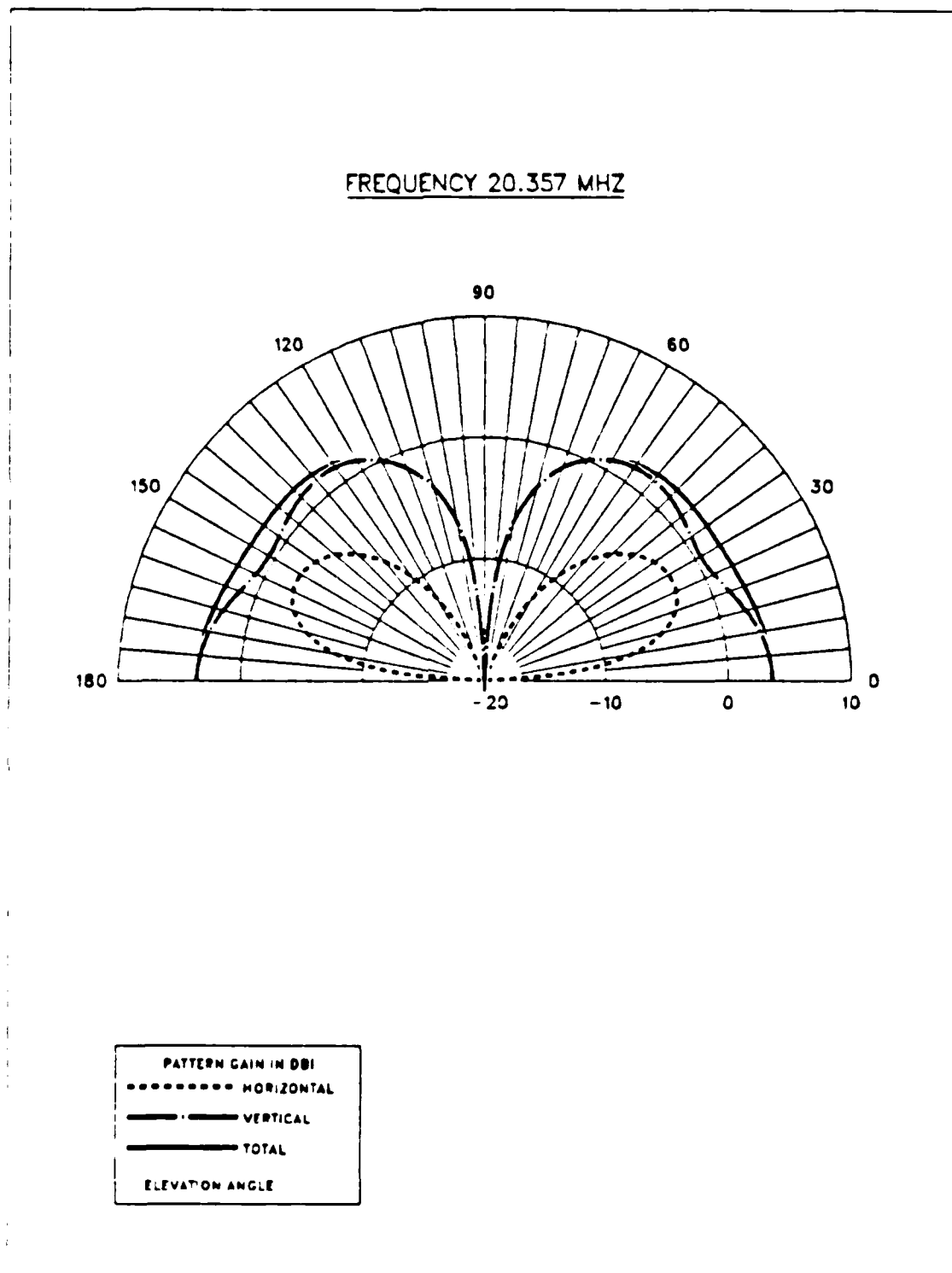


Figure 3.12 Elevation Pattern at 45° Azimuth.

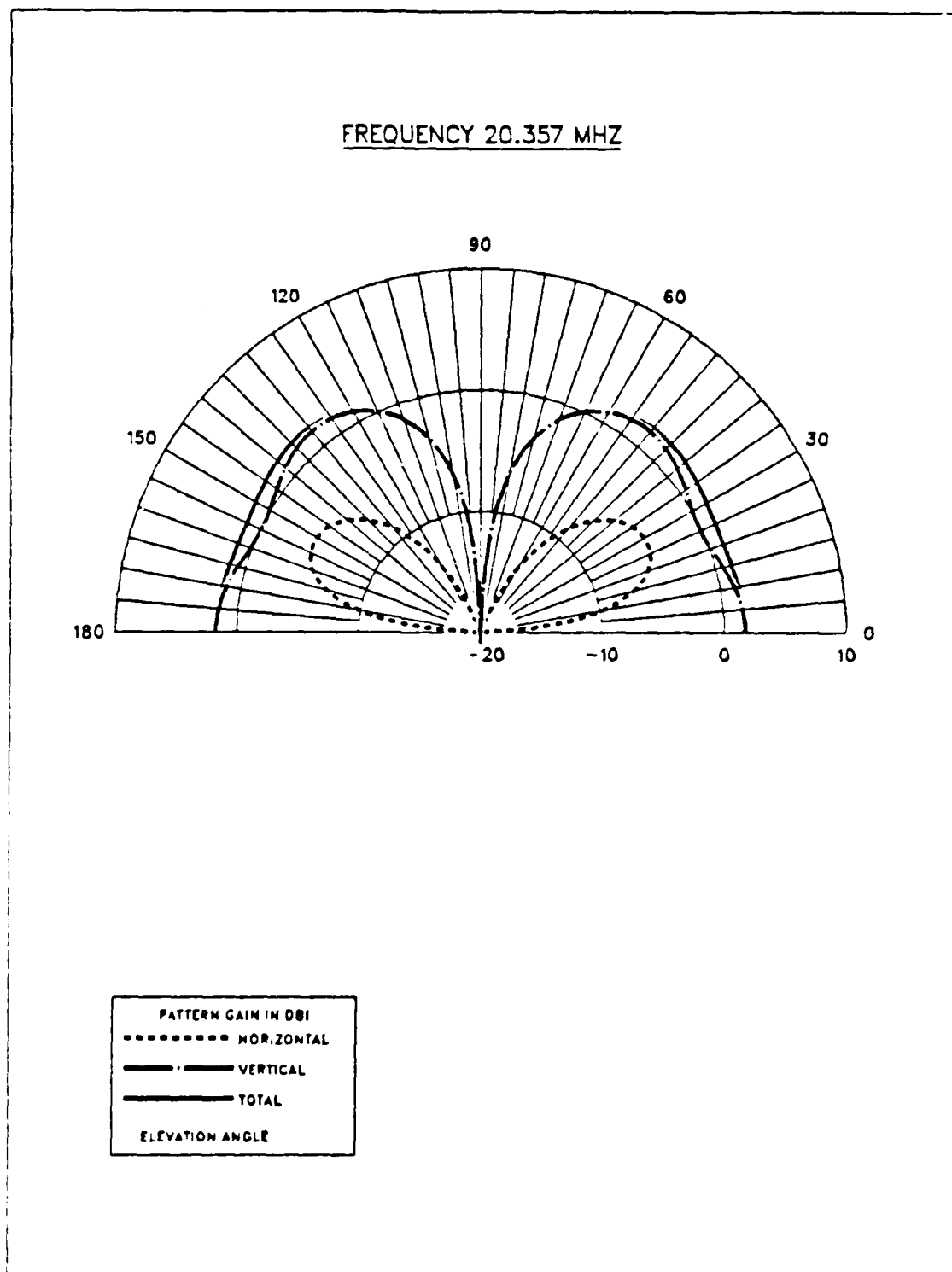


Figure 3.13 Elevation Pattern at 30° Azimuth.

FREQUENCY 20.357 MHZ

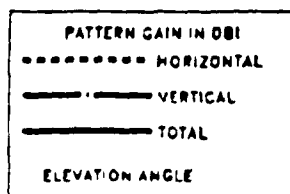
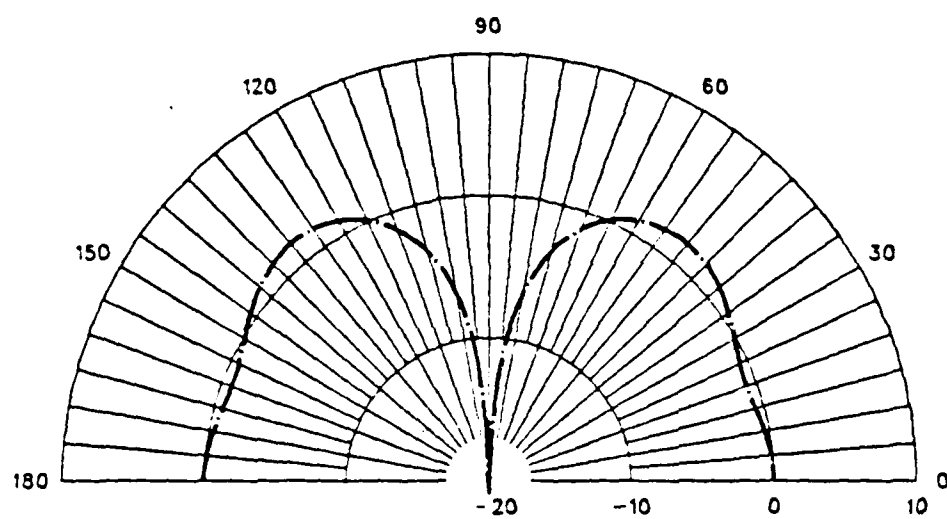


Figure 3.14 Elevation Pattern at 0° Azimuth.



#### D. NEAR FIELDS INSIDE THE SLOT

The distinction between fields at large distances and those nearer to the antenna is emphasized by subdividing the exterior space into two regions, the one near the antenna, called the "near field" or Fresnel region and one at a large distance, called the "far field" or Fraunhofer region. In this section, an explanation of the near field distribution is given.

The total electric field at any point in the vicinity of the slot is the sum of the  $E_x$ ,  $E_y$ ,  $E_z$  components of the electric field.

Inside the slot, only the  $E_x$  and  $E_z$  components exist. The value of  $E_z$  ranges from 0.008 to 0.025 V/m and the value of  $E_x$  from 0 to 0.0004 V/m.

Thus, the total electric field is controlled by the  $E_z$  component of the electric field, which is the dominant component and is plotted in Figure 3.15.

As shown in Figure 3.15, the peak magnitude of the electric field decreases as one travels from the center of the slot to the edges of the slot. The entire length of the slot consists of 56 segments, each one 0.125 meters in length.

The value of E-peak magnitude in Volts/meter has a minimum every 8 segments, counting from the edges of the slot. This is due to the fact that every 8 segments there is a junction of the upper and lower wires of the large side of the slot with the rest of the structure, since the bulkhead is modeled by wire grid.

In Figure 3.16 the distribution of the near electric field for one segment is plotted for various distances in the  $z$  direction from the middle of the slot.

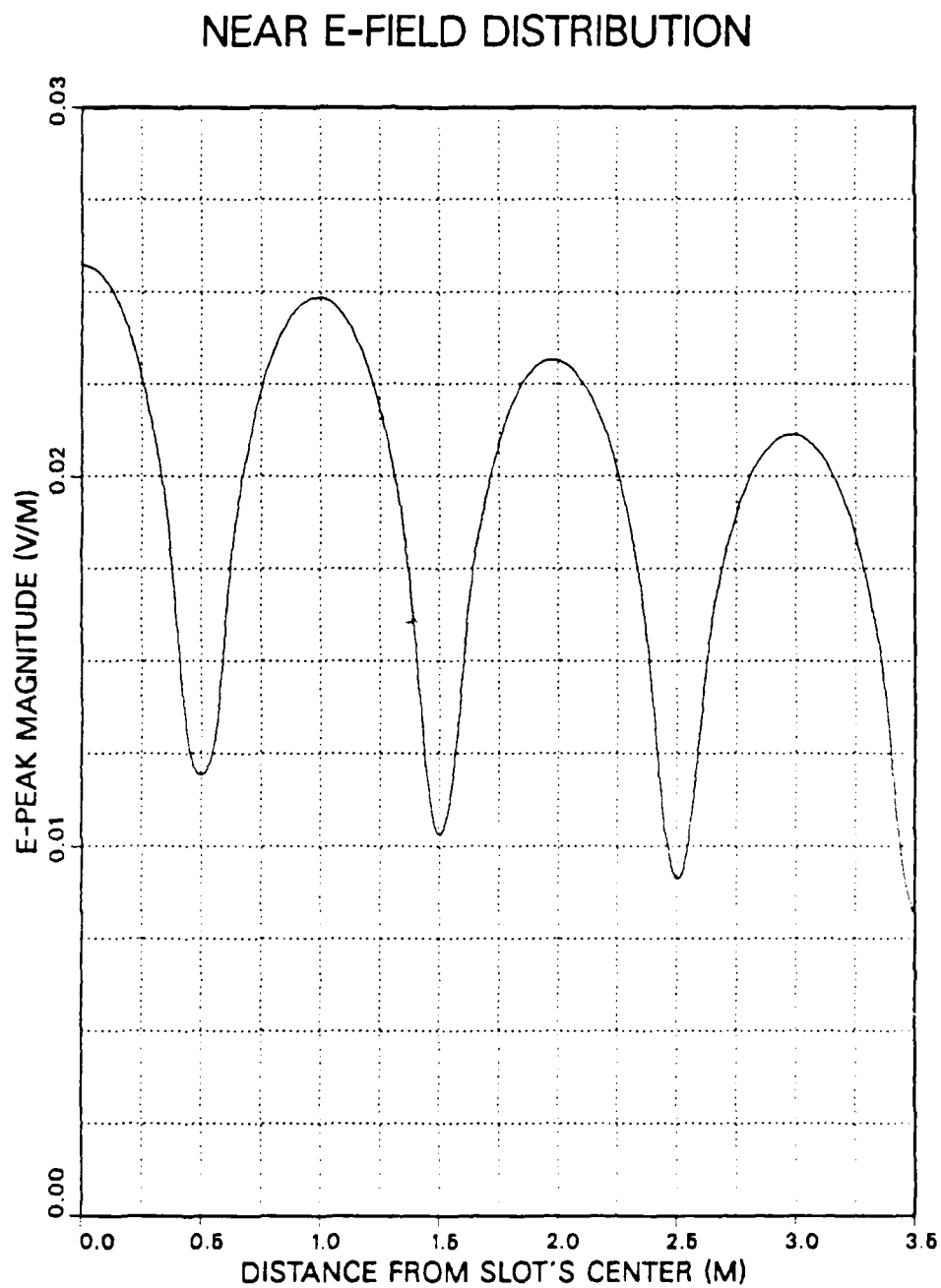


Figure 3.15 Near E-field distribution.

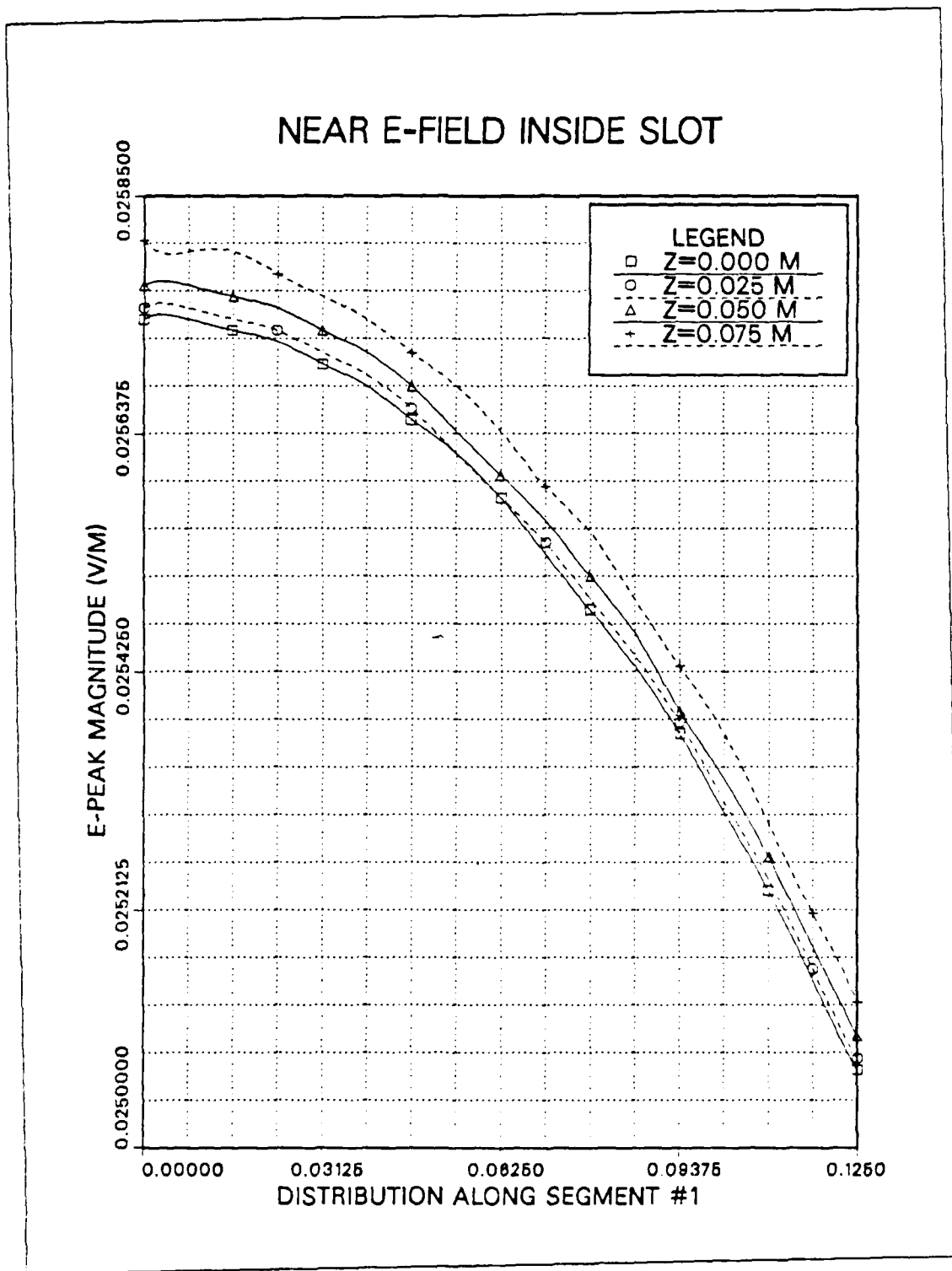


Figure 3.16 Near E-field distribution over one segment.

### E. AVERAGE GAIN CORRECTIONS

The average gain can provide a check on the accuracy of the computed input impedance. Over a perfectly conducting ground, the average gain should be equal 2 (accepted range 1.8 to 2.2).

In this case, for the frequency of 20.357 Mhz, the average gain is 1.7215 and means that 86% of the power leaving the antenna is radiating as the space wave. Although the structure is over perfect ground, the average gain, as mentioned, is 1.7215 and this indicates that the input impedance is inaccurate, probably due to the different segmentation of the wires used in simulating the structure.

Since there are no ohmic losses, a more accurate input impedance can be obtained as:

$$\text{Radiated power} = 1.2 \times (\text{average gain}) \times (\text{computed input power})$$

or

$$= 1.2 \times (1.7215) \times (0.7142 \times 10^3)$$

or

$$= 0.61475 \times 10^3 \text{ Watts}$$

The above result satisfies the condition  $P_{\text{rad}} < P_{\text{in}}$

$$\text{Radiation resistance} = 2 \times (\text{radiated power}) / |I_{\text{source}}|^2$$

or

$$= 2 \times 0.61475 \times 10^3 \times 3.2184 \times 10^{-6}$$

or

$$= 383 \text{ Ohms}$$

Since the input power used in computing the gain is too large by 0.65 dB the gain can be corrected by adding this factor.

$$\text{NEC calculated gain}_{\text{db}} + \text{correction}_{\text{db}} = \text{true gain}_{\text{db}}$$

or

$$2.359 \text{ db} + 0.65 \text{ db} = 3.009 \text{ db}$$

or

$$1.7215 \times 1.16 = 1.999$$

Thus, the corrected gain is 1.999

## IV. CONCLUSIONS AND RECOMMENDATIONS

### A. CONCLUSIONS

This thesis developed a wire grid model for a resonant halfwave slot antenna which was used to determine the impedance characteristics and radiation patterns of a slot antenna over the HF frequency range of 5 - 30 Mhz.

The reason for conducting this performance evaluation was to determine if this approach to survivable antennas is feasible enough to be implemented in future ship designs.

In the process, several wire grid computer models with various mesh densities and segments of different lengths were created. There was no noticeable difference in the performance evaluation between the models. Thus, the final model selected required less CPU time and gave reasonably good results. It should be kept in mind that minor corrections had to be made, so that the average gain requirements could be met.

From the input impedance values obtained using NEC, it appears that this wire grid model can be used to obtain reasonable input impedance values, which are, in general, in agreement with the theoretical values of slot antennas in infinite planes. It was proven also that the input impedance is a function of feed-point location along the slot's length and that an off-center feed is required for impedance matching to standard transmission lines to assure efficiency in the transfer of power.

Comparing the radiation patterns of the modeled slot to those of a reference dipole, the slot gave omnidirectional coverage (no nulls) and that the maximum intensity is about 3db better than that of the dipole.

Near fields inside the slot were calculated also. The maximum-to-minimum variations as one goes from edge to edge of the slot need to be further investigated. This variation is due to the fact that the wire grid is only an approximation to a planar surface for currents on that surface.

From the results obtained, it is seen that Numerical Electromagnetic Code, with its wire grid modeling ability, is an effective tool in analyzing antenna structures of this kind and should be further used in the application of survivable, compact and low-profile HF shipboard antennas.

In this study, 578 segments were used (not counting the one required to represent the voltage source which feeds the slot antenna).

The obstacle for a more detailed investigation of this subject is that structures having a large number of segments require large computer storage area and long execution time leading to the requirement of a faster and larger computer, such as a CRAY-XMP.

## **B. RECOMMENDATIONS**

One recommendation for further investigation is to place some type of dielectric material in the slot region for structural support and for sealing against the environment.

Another recommendation is to investigate the performance of cavity-backed and boxed-in slot antennas, two of which are shown in Appendix B.

The performance evaluation of cavity-backed or boxed-in antennas was the primary scope of this thesis but because of the long execution time required -5 hours- and the inability of NPS computer to provide the extra memory space required, these models were abandoned.

The concepts of multifunctionality and multicoupling for this kind of antenna should also be investigated.

## APPENDIX A

### A BRIEF DESCRIPTION OF NEC

#### 1. INTRODUCTION

Numerical methods based on integral formulation and solution are used by computer codes one of which is NEC -Numerical Electromagnetic Code- to analyze the electromagnetic response of antennas and or other metal structures.

NEC requires that antennas or other metal structures, with or without their environment, are to be modeled with strings of short, straight, thin wire segments or surface patches. These wire segments or patches should follow as closely as possible the geometry of the conductors of the antenna or the metal structure being modeled.

NEC can provide, by appropriate requests, information about the following quantities which evaluate the electromagnetic response of a specific antenna and or a metal structure.

- Input impedance
- Input power
- Antenna efficiency
- Radiation patterns
- Gain
- Coupling
- Near field values
- Polarization
- Currents
- Charge distribution

A model may include non-radiating networks and transmission lines connecting parts of the structure, perfect or imperfect conductors, and lumped element loading. A structure may also be modeled over a ground plane which may be perfect or not.

The excitation of the models is performed using a voltage or current source or an incident plane wave of various polarization schemes or a field due to a dipole.

NEC has been developed at the Lawrence Livermore Laboratories, Livermore California under the joint sponsorship of the Naval Ocean Systems Command and the Air Force Weapons Laboratory.

This code is suited to either antenna analysis or scattering and EMP studies.



## 2. DERIVATION OF INTEGRAL EQUATIONS

The derivation of an integral equation for a wire structure can be accomplished by writing the Maxwell's equations in integral form so that the scattered or secondary fields are given in terms of integrals over induced source distributions. By expressing the secondary field over loci of points where the behavior of the total field (incident or primary plus secondary) is known via boundary or continuity conditions an integral equation for the induced source is obtained in terms of the primary field. [Ref. 6: p. 7-1]

Two general classes of integral equations are obtained depending upon whether the forcing function is magnetic or electric.

It has been found that the magnetic field type of integral equation (MFIE) are more commonly employed for smooth closed surfaces and that the electric field type of integral equations (EFIE) are best suited for thin plate or shell geometries and wire structures.

The approximations involved in developing wire integral equations are:

- the circumferential current is negligible
- the circumferential variation of the longitudinal current can be ignored
- the thin wire or reduced kernel can be used in place of the actual surface integration

These integral equations can be solved using the Moments or Matrix Method.

## 3. THE METHOD OF MOMENTS

The method of Moments is a technique where an integral equation is reduced to a system of simultaneous linear algebraic equations in terms of the unknown current. Once the currents are known it is a fairly easy and straightforward procedure to determine the previously mentioned quantities which evaluate the electromagnetic response of the model.

The method of Moments experiences two limitations

- the amount of computer storage necessary for the impedance matrix and
- the amount of time required to compute the elements of the impedance matrix and to solve the resulting system of equations.

So, proper choice of the number and dimensions, relative to the wavelength utilized, of the segments and or patches is critical to obtain accurate and less CPU time-consuming results.

#### 4. NUMERICAL GREEN'S FUNCTION

With the Numerical Green's Function (NGF) option a fixed structure and or its environment may be modeled and the factored interaction matrix is saved on a file.

When new parts are added to the model in subsequent computer runs the complete solution is obtained without repeating the calculation for the entire structure. So the main purpose of NGF is to avoid unnecessary calculations when a part of the model will be modified one or more times while the environment remains fixed.

Another reason for using the NGF option is to exploit partial symmetry in a structure when such a symmetry exists. Such a partial symmetry may be exploited to reduce solution time by running the symmetric part first and writing a NGF file; the unsymmetric parts may then be added in a second run.

The NGF option is also used to save results from large time-consuming runs for further use. [Ref. 7: p. 89]

APPENDIX B  
CAVITY-BACKED AND BOXED-IN SLOT ANTENNAS

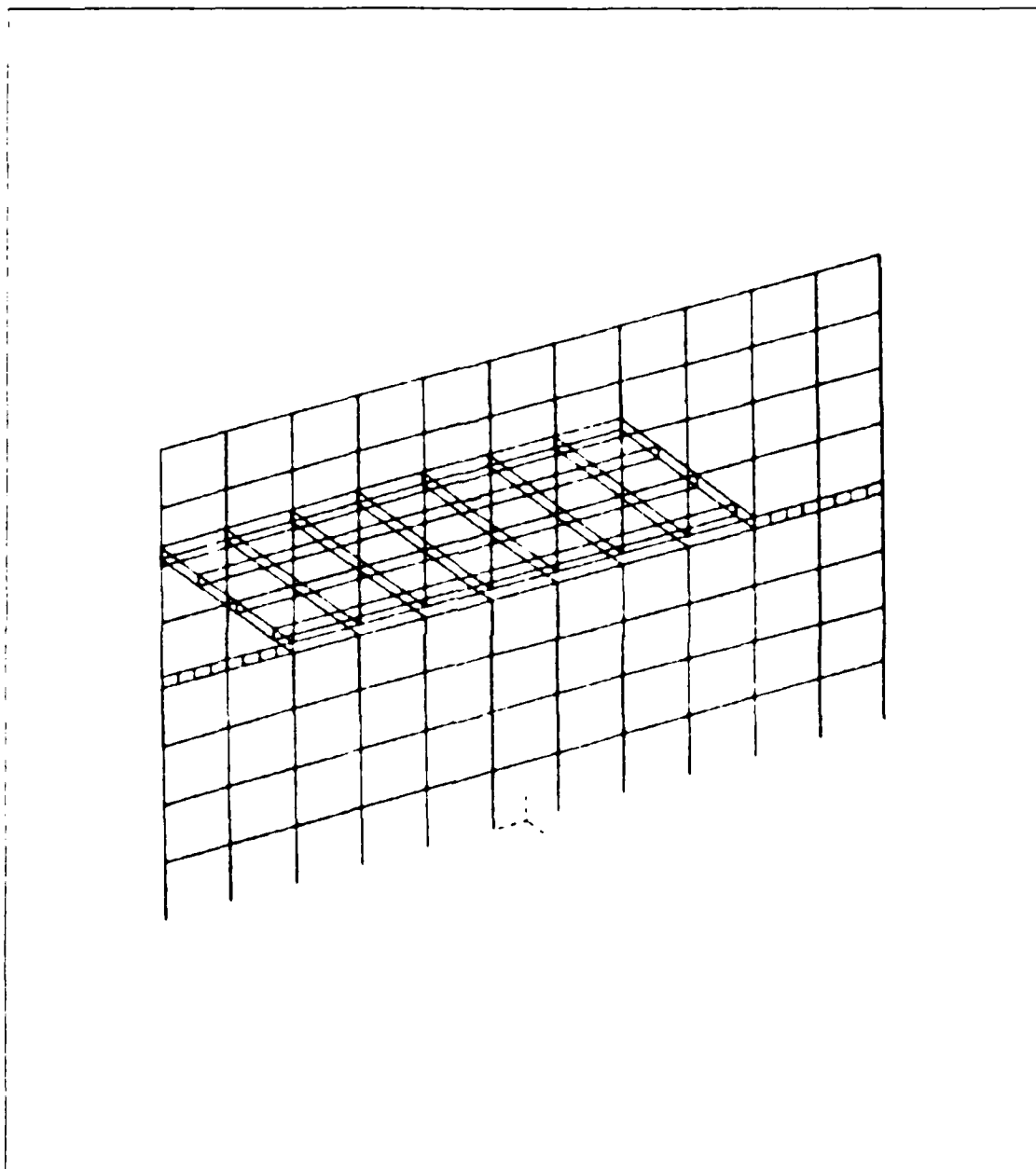


Figure B.1 Back-cavity Slot Antenna.

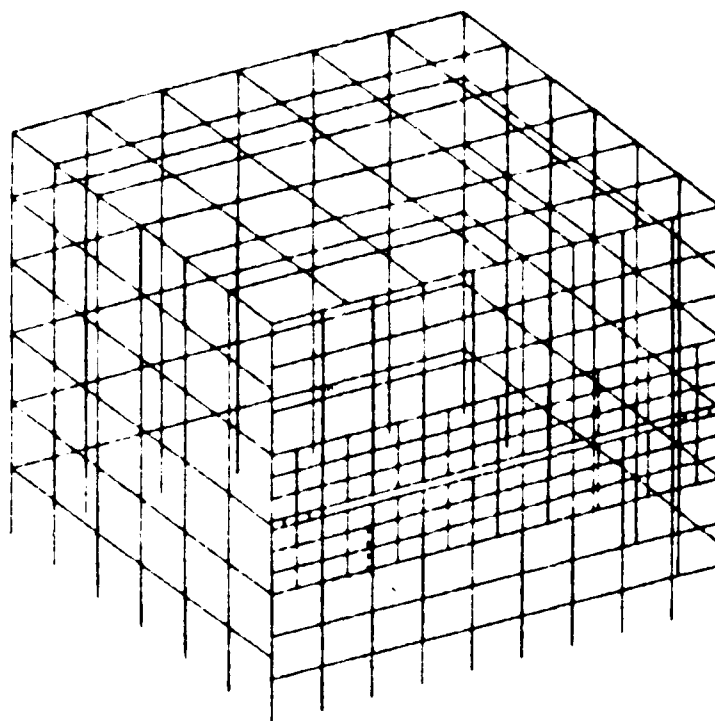


Figure B.2 Boxed-in Slot Antenna.

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